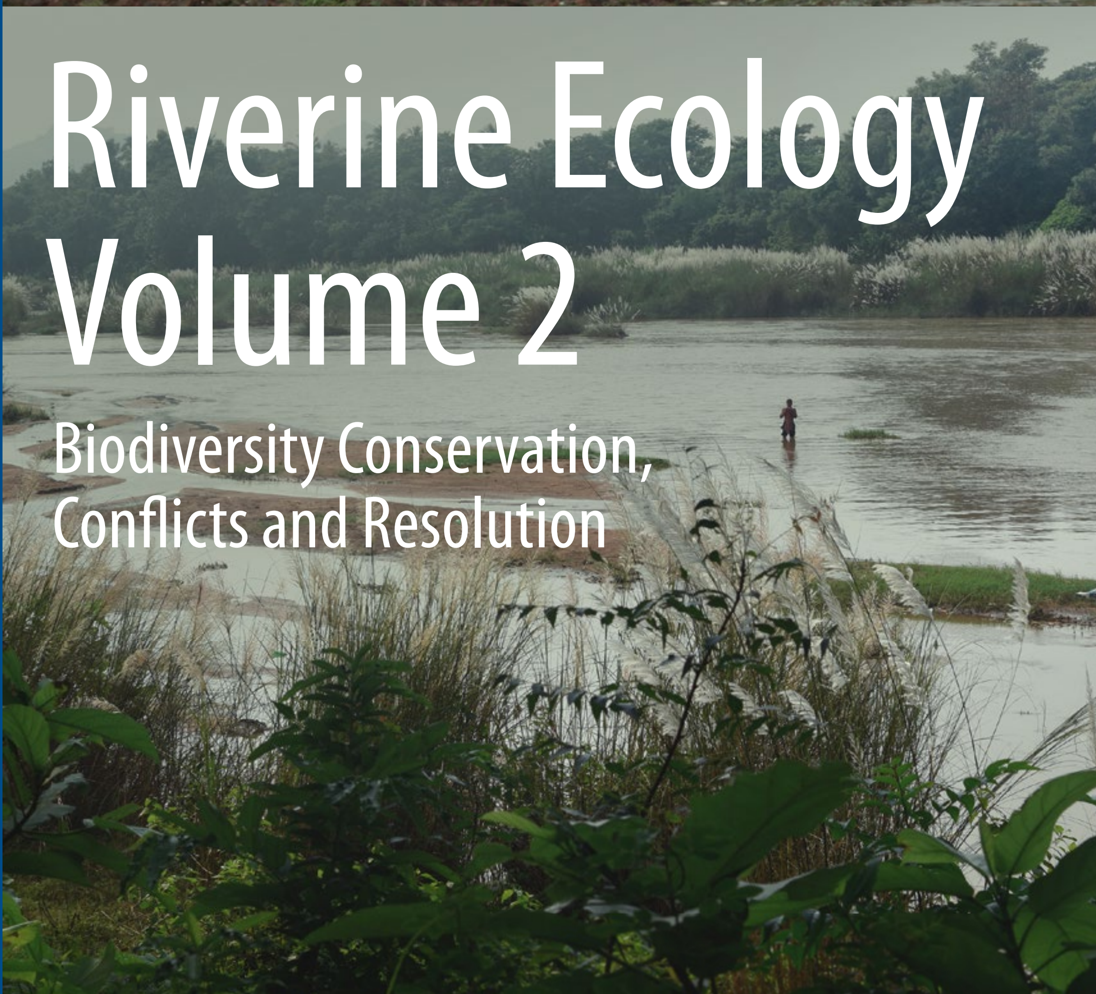
Susanta Kumar Chakraborty



Riverine Ecology Volume 2

Biodiversity Conservation, Conflicts and Resolution

Springer

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To all of my teachers and mentors
who taught me with precious academic
stimulation and exposed me in the gamut of
nature to love and learn her mysteries

Preface

Since times immortal, rivers have been recognized as the lifeline of human civilizations by acting as the provider of almost all kinds of resources required for the sustenance of human beings. Human beings by virtue of their intelligence and innovative knowledge had tried to reap the benefits provided by rivers for centuries; neglecting and ruining the ecological balances of rivers and other associated aquatic ecosystems maintained by way of its ecosystem functioning and in the process contribute profusely in disrupting the biogeochemical cycles and cause hindrance in the sustenance of sustaining mother earth.

Biodiversity is the potential and necessary structural ingredient for the functioning of river, coping up with natural and human-mediated ecological changes. Riverine ecosystem with a network of streams exhibits ecological variability over space and time, displaying high degrees of longitudinal, lateral, and vertical connectivity among the aquatic networks.

Writing up this book had an intention to cover different dimensions of riverine ecology giving due emphasis on synergistic impact of pollution-mediated environmental perturbation on the riverine ecosystem in general and on biodiversity in particular. Simultaneously, biodiversity potential of the riverine networks in aiding the resistance and resilience of riverine ecosystem functioning and their synergistic effects on ongoing environmental perturbations have been addressed, citing case studies mostly from tropical environment of the state of West Bengal, India. More stress was laid on explaining the adaptabilities of the organisms against changing ecological conditions. Besides, several methodological tools pertaining to the studies of water and its biological wealth with underlying identification and documentation principles, eco-monitoring of environmental changes, biodiversity assessment and conservation especially by people's perceptions, ecological impacts of human intervention, restoration and conservation strategies adhering to basic ecological principles, and bio-eco-statistical formulations have been made. However, not only have the teaching and research on general biology developed at a fast pace in the past couple of decades but new methods and topics have also been adopted in subjects like ecology and limnology. Besides, burning global issues such as climate change and biodiversity have become the focal points in research and planning, and they have finally entered into the political arena.

This book is about the distribution and abundance of different types of organisms and about the physical, chemical but especially the biological features and interactions that determine these distribution and abundances. This book explores the challenges in linking up the biodiversity wealth of rivers with other ongoing burning sociopolitical issues in the global, national, and regional perspectives in order to develop appropriate eco-management strategies for the governance of the rivers (sustainable and equitable distribution of fresh water with other resources) highlighting the advantages and disadvantages of various approaches of such management practices to make them suitable and acceptable for the coming days.

This book attempts to highlight the distinctiveness of river ecosystem, tracing troubled relations with power and politics for centuries centering on the human-mediated perturbation and onslaught on this sensitive, but productive landscape for exploitation of biodiversity. The publication of this book also has intended to draw attention to and also enlighten academicians, researchers, administrators, and planners about the multidimensional aspects of river ecology from both theoretical and practical views. This book is dedicated to those interested in the natural and social sciences, especially for the students and researchers of ecology, environmental sciences, environmental planners, and administrators, for their understanding of the elements pertaining to the functioning of river ecosystem, sensitivity, and vulnerability through different, already established relevant underlying scientific principles, hypotheses, and theories, and different strategies of eco-restoration alongside sustainable eco-management of rivers and aquatic ecosystems with an emphasis of socioecological perspective.

Considering and recognizing the critical roles played by the rivers in promoting and boosting the growth of human civilizations across the globe, human beings have been interacting with rivers and their floodplains over millennia. A multitude of different natural and human-induced stresses on different river ecosystems across the globe and the resultant harmful effects on the physical, chemical, geological, and biological components of rivers and different methods of rehabilitation, reclamation, remediation, and restoration for the integrated and holistic eco-management and nourishment have been addressed giving emphasis on socio-economic-political perspectives. Society attaches many values on the intellectual creativity as an essential component to elevate the excellence in science and that excellence in science in turn appears to become an essential factor promoting most effective and cost-efficient management of river resources.

The entire book has been written putting more emphasis on five major keywords: ecology, biodiversity, pollution, sociopolitical issues and conservation (restoration and methods). An overview of the material is given at the beginning of every chapter in the form of an abstract. The subject "**river ecology**" has been dealt with by detailing its multidimensional facets with subject contents distributed in six elaborate chapters starting with **Chapter 1**, **Introduction**, briefly highlighting main objectives and contents of this book; **Chapter 2** discusses **physico-chemical parameters** in respect of temporal and spatial variations. **The subject biodiversity** deals mainly with the inventory of the basic biodiversity components and ecological information of river biodiversity, which include biodiversity of macrophytes, microphytes, and microbes (bacteria and fungi). **Chapter 3** mainly discusses on **eco-ethological aspects of river fishes, and Chapter 4 attempts to project the diversity of wildlife which abound the main riverine flows, in the riparian forests, and also other terrestrial biomes in and around the river basins**. **Chapter 5** deals with **river pollution**, mostly highlighting the major sources, properties, and ecological impacts of different pollutants causing perturbation in river ecosystem; **Chapter 6** deliberates the relationships of **Land uses, flood plains, and dams with rivers**, and different anthropogenic interventions on riverine flows such as construction of dams, dikes, interlinking of rivers, irrigation channels, power plants and also attempted to point out conflicts there off because of their environmental consequences. **Chapter 7** dealing with **river-politics and conservation** focuses on sustainable river management and conservation highlighting the present state of problems and prospects. **Chapter 8 discusses river restoration** of eco-degraded riverine systems citing case studies following existing and newly developed conservation strategies with the involvement of socio-political-economical components pertaining to river resource shadings and sustainable river management. **Chapter 9** on **methodologies** deals with river studies ranging from taxonomic documentations, statistical analyses, pumping methods for assessing water availability, biodiversity studies, and several conservation methods especially through peoples participation such as Sacred Groove, Participatory Rural Appraisal (PRA) methods, and the last chapter **(Chapter 10), Conclusion, elaborately sums up the entire subject matters of the book touching on the salient aspects** of river biodiversity, fish, wildlife, pollution, land uses, politics, restoration, and methods for eco-assessment and conservation.

This book is organized with an introductory chapter (Chapter 1) preceding nine other chapters detailing the subjects like biodiversity (flora, fauna-zooplankton, benthos, fishes, wildlife), fish and river, wildlife and river, land use changes, river politics, eco-restoration, sustainable conservation, and relevant bio-mathematical and action-oriented pro-peoples methodologies for eco-assessment of river ecosystem.

After Chapter 1 (Introduction), each of the next eight before an elaborate chapter as **Conclusion**, is organized as the following: it begins with an abstract, followed by the main contents presented under different headings and subheadings incorporating major developments in the subject in the international panorama substantiated by regional case studies. The entire discussion ends with a brief conclusion followed by references and recommendation for further readings. The introduction part of each chapter begins by explaining why the knowledge on the ecological functioning of rivers and their integrations with the history, culture, and economics of human beings are needed for understanding river science and management. Besides, significance of the rationality and relevance of the contents of other chapters has been highlighted to justify their inclusion in this book. Organizing the book in this application-oriented approach is expected to allow the readers to easily access and locate information along with pertinent interpretations that are needed for their understanding of the subject matters of the relevant chapters.

Chapter 1 Introduction

This chapter pinpointedly touches the salient features of all the chapters within this book, highlighting major subjects.

Chapter 2 Biodiversity: Concept, Theories, and Significance in River Ecology

This chapter at length discusses the regional riverine system in the context of international river biodiversity research focusing on macrophytes, microphytes, zooplankton, benthos, insects, and even fishes and their diversity, distribution, trophic position, and functional roles. The role of biodiversity in the functioning of river ecosystems and providing various ecosystem services are not confined to providing water and biodiversity components, but huge biomass within the river is instrumental for the assimilation and removal of wastes dumped within the rivers by the anthropogenic activities. It is the time to develop proper understanding on the complex relationships between riverine biodiversity and ecosystem services. Besides, several conservation strategies for the riverine biodiversity have been coming up through several trial and error basis depending on the agroclimatic conditions of the regions which include natural breeding and nursery grounds for fishes and other commercially important shell fishes, the protection of pockets of habitats for induced breeding, river ranching, etc.

Rivers support the life of galaxy of fauna including an array of wildlife (higher mammals, smaller mammals, reptiles, testudines, crocodiles, birds, etc.), both aquatic and terrestrial, inhabiting in the riparian forests within river basins. Since the 1980s, especially after the Stockholm Conference in the year 1972 on man and environment, the field of biodiversity grew and flourished forming an amalgam of several disciplines of sciences and even social sciences, especially to ensure sustainable conservation within the political and economic realms influenced by the science through policy formulation. Sustainable development is being recognized as the best option for meeting the both ends, conservation of biodiversity and elevating the standard of living of human beings by judicious utilization of bioresources.

Chapter 3 Ecology of Fishes of Rivers: Functional Roles

Although the science of fishery in the riverine ecosystem emerged around century back with the thrust areas of identification and taxonomic classification of fishes, which were followed by the studies on biology, life cycles, migration, and relationship with other aquatic organisms, the conservation approach in fishery science in India that gained momentum after the **1980**s, alongside the conservation of some iconic species such as gharial and dolphin. This presenting data on fish and fisheries of river system mainly emphasize on the functional roles of the fishes toward ensuring the stability of river ecosystem, mainly by projecting several recent studies on the ecological guilds of fishes, impact of temperature stress on the fresh water carp species in view of glibal climate change, roles of fishes not only as the prime driver of aquatic food webs but also their roles as ecological indicators for the eco-monitoring as well as their utility for the riverine eco-restoration.

Chapter 4 Diversity and Conservation of Wildlife Associated with Rivers: An Eco-ethological Analysis

This chapter deals with wildlife (amphibians, reptiles, birds, and mammals), not only restricted on projecting the diversity of wildlife with brief classificatory scheme but also attempted to provide information on their evolutionary origin, geological background of their distribution, relationships among the existing wildlife of different continents, behavioral manifestations and the determining eco-physiological reasons, and conservation strategies. It should be realized that rhinos, swamp deer, and elephants and many other large herbivores dependent upon the rivers are as much a part of the river's biodiversity as the fish and dolphin. It is surprising that the birds entirely dependent upon the rivers have received little attention.

Chapter 5 River Pollution and Perturbation: Perspectives and Processes

The river ecosystems all over the world have been greatly perturbed by human activities. The chapter at length discusses on the sources, and properties of the pollutants and their mode of action on the living and nonliving structural components of rivers. In order to deal with the scarcity and deteriorating qualities of freshwater of rivers, water in view of ongoing industrialization and urbanization, as well as high input from modern agriculture, may lead to considerable changes in water quality characteristics in urban areas as well as in rural areas. The needs and principles for monitoring such changes are discussed

Chapter 6 Landuse Changes: Floodplains, Dams, and Reservoirs – Integrated River Basins Management

It is also shown that large-scale water regulation projects, for example, dams, may create conflicts between proponents for a utilization of the regulation capacity for hydropower generation policies and those favoring the use of the regulating capacity for agricultural purposes.

Chapter 7 Ecobiopolitics, Policies, and Conservation Strategies of Rivers

Besides formal procedures, a number of informal tools in terms of economic sanctions and the use of nonformal institutions may be of considerable importance both for avoiding and for the handling of conflicts. Conflict management is, however, complicated by a number of circumstances. Illustrations of practical experiences from developed as well as developing countries show that political interference and well-established routines in the administrative setup might, indeed, underline conflicts or hamper a rational management. Likewise, it is argued that unpredictable conflicts may complicate a smooth conflict management. It is argued that with increasing socioeconomic development, it is necessary to pay due attention to environmentally sound planning and evaluation procedures. By applying an ecosystem view on resource utilization, the potentials and limitations can be rationally assessed with regard to a sustainable utilization. A sound conceptual framework is also relevant only from a strict environmental point of view. Such a perspective is also called for in the efforts of designing new projects and adjusting existing ones so that human efforts are not drained and financial investments become cost-effective.

Chapter 8 Eco-restoration of Rivers

The continuous and concerted efforts of the human beings to derive as maximum as possible economic benefits from the existing global water resources have resulted for the innovation, invention, standardization, and implementation of an array of technologies for building up numerous built structures in and around river flows, alongside conceiving, developing, and applying operating policies for controlling the river flows and non-judicious exploitations of its resources. All those developments have proved their efficiencies by facilitating navigation; providing higher quantities of reliable water for the purpose of agricultural, industries, and municipal water demands; generating hydroelectric power and energy; and providing increased flood protection, recreation, and other benefits.

In order to harvest as maximum as possible economic benefits over the past half century, many of the rivers of the world have been converted into engineered waterways with the construction of dams, dikes, reservoirs, weirs, irrigation channels, etc. However, rivers and their floodplains have appeared to be the most threatened landscape of the world because of the intimate relationships and dependence of human beings on rivers, which have become stressed from the excessive use, and misuse of their resources, as well as discharging of considerable amount of both point and nonpoint pollutants into the rivers.

Chapter 9 Methodologies for the Assessment of River Ecosystem in Southern West Bengal, India

This chapter includes several subject components pertaining to the assessment and conservation of river ecosystem highlighting some innovative research approaches, which have been developed involving the local people of the area.

Chapter 10 Conclusion

This chapter tries to accommodate the major focus of each chapter, addressing different dimensions of riverine research on biodiversity and eco-management.

Justification of Writing This Book

Ecology, basically the study of the interrelationship between species and their environment, involving such areas as predator-prey and competition interactions, renewable resource management, evolution of pesticide-resistant strains, ecological and genetically engineered control of pests, multispecies societies, plant-herbivore interacting systems, and so on is now an enormous field. The emphasis throughout this book is on the practical application of ecology with the prime objective of unraveling the underlying mechanisms involved in the biological processes for explaining and interpreting the ongoing ecological processes within and also outside of river ecosystem. The book has tried not only to accommodate several pertinent components centering around the riverine biodiversity, its ecology, environmental stresses out of pollution, changes in the land use and development of built structures, and sharing of benefits from the river in the face of ongoing international, national, and regional conflicts among the beneficiary, stakeholders, and social activists, but also to justify the inclusion of the vast canvas of issues pertaining to the biodiversity wealth, crisis, conflicts, remedies, and methods.

As the ecology of rivers all over the world, especially in the developing countries, is under peril, the protection of riverine flows along with all structural components (living and nonliving) is the need of the hour. After realizing that freshwater riverine flows representing a tiny fraction of earth's landscapes has become the lifeline of human beings, scientists, ecologists, and environmental planners have been trying to assess these threatening trends and their root causes in order to take challenge of not only identifying such deterioration of river environmental qualities but also to arrest them. **This integrated interdisciplinary approach** enables chalking out strategies toward a sustainable future of riverine ecosystems. Replacing of lost riverine ecosystem services with economic and technological development-based services has appeared to partially meet the materialistic thrust of human beings, but it seems to be increasingly difficult in the present pace of increasing economic and ecological turbulence.

Despite the monumental achievements in the fields of science and technologies applicable to rivers and associated aquatic landscapes, during the last century, natural disasters like floods and droughts leading to disruption of ecology and economies can no longer be ignored, and such experiences and knowledge derived out of it, can be used to make ecological assessment of the evil effects of pollution, habitat alteration by dam and like built structures, and constructions that jeopardize the basic ecosystem fabrics of river ecosystems. The challenge to combat the ongoing onslaught on rivers and their precious biodiversity is compounded by the unprecedented levels of change in nature which are anticipated to happen over the coming century especially by way of global climate change, population explosions paving the way for more disparity in resource sharing and demographic non-equilibrium, economy and human-centric technological development.

This book reviews the current scientific developments to make them useful for sustainable river management and to ascertain the society to learn its way into an uncertain future. It starts with proper evaluation of riverine water, its properties, basic ecological principles pertaining to biogeochemical cycling, assessment of the geohydrological and biodiversity potential and characteristics, and the trend of eco-degradation within riverscapes so that baseline research information can be generated to support and strengthen the mitigation measures not only to arrest the ongoing damages but also to restore the function of environmental flows and ecosystem services in riverine systems. The scientific perception, realization, and understanding considering the potential of the ecology of freshwater riverine system which was developed century years back as the biologically productive and sensitive running water ecosystem for catering to the need of human beings by providing water and food, alongside shaping the sociocultural profiles of a region. The quest of human being for unraveling the mysteries of river and its associated landscapes have not only been restricted to studies on food resources obtained from rivers but also on the changing ecological status of it with special emphasis on environmental perturbations in the backdrop of the River Continuum Concept.

This book goes a long way toward strengthening the prevailing international approach toward presenting the state-of-the-art information on ecology of riverine networks in tropical environmental condition, representing a unique bio-geographical sector in the eastern part of the mega diversity tropical country, India. Throughout, the various chapters deal with a wide variety of directions, mainly centering on ecology, biodiversity, perturbations, and management.

In a number of ways, it is increasingly difficult to separate scientific pursuit from an emotional and aesthetic bond in unraveling the mysteries of interlinkages and interdependence of different structural components of rivers, their intricate interaction pathways, and eco-management (conservation ethos and rehabilitation practices). In the quest to develop a logical set of principles in order to interpret the diversity and complexity of the riverine environment, this book is an attempt to communicate the already developed knowledge and understanding on multidimensional subjects in a holistic but as simple as possible way. Although much emphasis was laid on depicting the regional information with an Indian flavor, much endeavor was put on global perspective for developing the concept, hypothesis, and theories pertaining to riverine ecology so that useful guidance in the development of core understanding that is required if management activities are to yield sustainable outcomes.

This book covers a wide range of topics dealing with the ecological interpretation of riverine biodiversity with special emphasis on fishes and wildlife and trend of environmental perturbation due to the harmful impacts from a multitude of toxic substances and also focuses on the fate of all those pollutants and contaminants, different challenges and methods for eco-restoration processes, societal conflicts and politics in respect of water sharing and maintenance of water quality, and different traditional and modern approaches toward the monitoring and conservation of rivers and their resources. From this book, readers are expected not only to learn about the recent outcomes of river biodiversity in an ecological perspective in the face of ongoing threats from pollution and other human-mediated developments (high-tech agriculture, urbanization, industrialization, etc.) but also to understand the basic underlying ecological principles for undertaking sustainable eco-management strategies.

Midnapore, West Bengal, India Susanta Kumar Chakraborty

Acknowledgment

Two key words, river and biodiversity, have emerged as the buzz words in the gamut of natural sciences mainly because of their close association with man and as the provider of life supporting commodities for the fruitful survival of the human beings. The significant contribution of these two important gifts of nature has prompted me to write this book, *Riverine Ecology (Volume II): Biodiversity Conservation, Conflicts, and Resolution*.

In the process of writing this book, I had the privilege to have considerable help, support, and suggestions from various persons across the globe. I owe my gratitude to all of them.

In acknowledging a few of such supporters of me, I must extend my regards to the authorities of my institute, Vidyasagar University, Midnapore (West), West Bengal, India, which made it possible to enable me to pursue such time-consuming and painstaking work by providing necessary facilities. Secondly, it is the time for me to recognize and render my best regards to all my senior advisers and my sincere thanks to all my junior researchers, well-wishers, and friends for their valuable support throughout the entire journey of writing up the present book since the time when the idea was first conceived and was subsequently crystallized on getting the approval from the publishing house, Springer, USA.

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(4) environmental perturbations, and pollution in the river ecosystem; (5) land use changes and relevant ecological consequences; (6) sociopolitical perceptions in sharing the benefits from rivers and conflicts there off; (7) modern approaches of eco-restoration process and sustainable eco-management elaborating relevant methodologies; (8) in addition, the last chapter has dealt with a brief survey of different developments pertaining to the study of riverine ecology with special emphasis on eco-monitoring and conservation. The first chapter as introduction and last chapter (Chapter 10) as conclusion have attempted to discuss most of the thrust areas that were elaborately highlighted in eight other chapters. I shall be failing in my duty not to name some of my research students such as Tridip, Manjistha, Sujoy, Kishalay, Md. Abdullah-Al Helal, Santu, Subhashree, Sayan, Sankarson, Santanu, Ram, Srinjana, Arundhuti, Arijita, Tilottama, Joydev, Sankarson, Ritabrata, Hirulal, Anindita, and Jayanti for their active support and secretarial assistance throughout the entire period of this book preparation. My special thanks are due to Dr. Tridip Dutta, my Ph.D. student, Dr. Ritabrata Roy, my post postgraduate student and Mr. Jagadish Mahata, supporting staff of Vidyasagar University, Midnapore (West), West Bengal, India.

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Although the author writes a book, if it is a text book, it does not or should not belong as a product of author alone. Thousands of pieces of information generated by a multitude of research activities have been used in one form or another to enrich the subject of each and every chapter of this book. Therefore, writing up a research-based text book is not that easy, as it appears to be, because it needs not only highlighting the present research information on the relevant subjects but also presentation of a comparative view of the earlier research outcomes undertaken by different researchers from different corners of the globe. Simultaneously, already established research ideas or findings should be paid proper recognition.

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Contents

About the Author

Susanta Kumar Chakraborty Professor of Zoology, Vidyasagar University, born on 31 July 1960, has been in active research since 1982 after completion of his M. Sc. in Zoology from Calcutta University. His research preferences center on subjects like Ecology (Coastal, Mangrove, Freshwater Wetlands, Rivers, and Estuaries), with an emphasis on Biodiversity and Ecosystem dynamics. He has also been associated with action research on the integration of rural biotechnologies for the environmental management, ecorestoration, and livelihood generation. He completed his M.Phil. in Environmental Science and Ph.D. in Marine Science from at Calcutta University in 1984 and 1992, respectively. He has been imparting teaching spanning a period of more than three decades mostly in the postgraduate level covering different aspects of Zoology in general and Ecology/Environmental Science in particular. So far, he has successfully supervised the Ph.D. thesis of 39 researchers, published around 186 research papers in various reputed international and national journals, written a couple of books, completed more than a dozen of research projects including consultancy projects on Environmental Impact Assessment, and visited several countries such as Australia, USA, Hong Kong, Belgium, France, and Bangladesh in connection with his academic commitments. He has delivered more than hundred of lectures in various Seminars, Symposia, Conferences, Workshops, Refreshers Courses, etc. in different parts of India and abroad highlighting his scientific thoughts and research achievements. Besides, he has shouldered a number of administrative responsibilities in his own university, such as Dean, Faculty of Sciences, Head of the Department, Member of the Executive Council, Member of the Finance Committee, Chairman of College Governing bodies, etc. and also in other universities as an Expert Member of Selection Committees, Academic Bodies, etc. alongside contributing as an Expert Member for several government departments like UGC, ICAR, etc. He has been associated with a number of scientific bodies in India and abroad as Life Member, and reputed journals as a member of editorial bodies. He has received a number of awards in recognition of his research commitments.

Chapter 1
Introduction

Abstract Rivers, large and small with all of their tributaries and streams, are considered as the lifeline of human civilization and are referred as being the circulatory system of the planet. Rivers across the world vary from one another based on mainly geomorphological features of the catchments and forming different eco-regions create templates of habitats for the settlement, growth, and proliferation of different biodiversity components in the course of the journey of rivers from their origin in the upstream to the end point of downstream at the meeting point with the sea. Since the earlier phase of the development of human civilization, rivers have been playing significant roles in providing both ecological and economic benefits to ensure the survivability of mankind in this mother earth by providing pure water for the all-round human activities (familial, social, urban, agricultural, and industrial) and also by triggering the growth and propagation of biodiversity components by providing sediments and nutrients obeying the functional operating principles of the specific natural ecosystem of the world. The diversity, succession, distribution, and seasonal dynamics of different biodiversity components including fishes and wildlife, their eco-physiological adjustments with the flowing water, and also an understanding of their steady responses to dynamism and oscillation of multi-scale habitat variables of large rivers due their spatial and temporal complexities have elaborately discussed emphasizing their functional roles and suitable conservational strategies for their protection.

Alongside emphasizing the ecological messages in respect of the synergistic impacts of human intervention coupled with natural changes on the regional riverine flows, imposing a multitude of stresses on different structural components of the very sensitive but productive riverine ecosystem, **this volume II** of **the book** *Riverine Ecology* aims at fulfilling the gap in the existing and relevant knowledge bases for the international community from the perspective of the tropical ecological dynamics of river ecosystems in promoting the biodiversity development and also in exhibiting resilience against ecological perturbation from a tropical country, like India.

Considering all those important ecological, economical, cultural, and social functions of rivers and their resource bases in different corners of the world, proper designing and implementing of appropriate eco-management strategies are the

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demand of the time for the protection, recovery, and careful management of the riverine ecosystem for the well-being of the human population.

These socioeconomic profiles of the regions are to be integrated in all eco-management ventures to ensure judicious use of water in meeting the optimum requirement and also to eco-restore the eco-degraded rivers. Such integrated and holistic ecological management require suitable methodologies (biological, physical, chemical, and technological) to quantify not only the resource bases but also the concentrations of pollutants in order to understand important ecological processes such as bioaccumulation and bio-magnification on aquatic inland water ecosystems.

Keywords Eco-regions in river · Biodiversity · Wildlife · Conservation strategies · Socioeconomic development · Biomonitoring · Pollutants · Eco-degradation · Eco-restoration · Methodologies

The mother earth is the only planet in the universe to support life which was first evolved around **4, 5000** million years back in the sea when this earth was appeared to be with bleak and desolate land endowed with cooling rock and violent volcanic activity. After a hectic climatic ups and downs in the primordial environment of earth (condensation of the gas and dust, followed by massive shrinkage enhancing the heat in the maximum level and resulting melting of rocks into gluey liquid followed again by cooling and solidification of the molten matter) and formation of liquid water through a chain of biophysical processes and with the diminishing of contortions, water began to accumulate in the depression on the earth's crust, resulting in the formation of oceans. In earth, experiencing the protective contribution of the invisible mantle, animal life began to ascend the ancient shores of the oceans and lakes, generally evolving into true land creatures. Evolution, a fascinating change in the life process resulting in the creation of new species, is often considered as a challenge and perhaps a threat to an organism. From these humble beginnings, animals and plants have come to occupy the different nook and corners of the earth. Even in the frozen habitats of the polar regions and the scorching sands of the great deserts, the life of animals and plants got adapted against any such environmental odds. Although innumerable number of species became extinct during the evolutionary history of the planet, living organisms tried to cope up with the continued environmental challenges (drifting continents, volcanoes, mountain up heal, the birth and death of oceans, and global climatic changes) to thrive and flourish with the evolution of new and newer species. However, with each of such change, the balance shifted a little but equilibrium was eventually restored. But, one species that also appeared in the earth through evolutionary process like others was the man, who could generate so many ingredients and inculcate them in the natural web of the global environment and disrupt the fragile natural balance of the planet was the man.

Rivers, large and small with all of their tributaries and streams are considered as the lifeline of human civilization and are referred as being the circulatory system of the planet. Rivers across the world vary from one another based on mainly geomorphological features of the catchments forming different eco-regions creating templates of habitats for the settlement, growth, and proliferation of different biodiversity components in the course of the journey of rivers from their origin in the upstream to the end point of downstream at the meeting point with the sea. Since the earlier phase of the development of human civilization, rivers have been playing significant roles in providing both ecological and economic benefits to ensure the survivability of mankind in this mother earth by providing pure water for the all-round human activities (familial, urban, agricultural, and industrial) and also by triggering the growth and propagation of biodiversity components by providing sediments and nutrients obeying the functional operating principles of the specific natural ecosystem of the world (Annandale (1922); Dudgeon (2000); Dudgeon (2000); Minshall (1984); Minshall and Minshall (1977); Minshall et al. (1982)).

Although almost all large rivers of the world have been serving for millennia as routes of transportation, sources of food, water, and energy, sinks for pollutants, etc., but, most of the rivers have been considerably eco-degraded by the direct or indirect activities of human beings. Despite the importance of large rivers, dearth of knowledge exist on the mode of functioning and quantum of services provided by the rivers to the human beings against the ongoing onslaughts on them by human activities. Considering all those important ecological, economical, cultural, and social functions of rivers and their resource bases in different corners of the world, proper designing and implementing appropriate eco-management strategies are the demand of the time for the protection, recovery, and careful management for the well-being of the human population.

Proper assessment of ecological changes and remediation of eco-degradation of river ecosystems are the demands of the day for ensuring sustainability of the threatened aquatic environment. This can only be possible by adhering strictly to the relevant ecological principles pertaining to such ecosystem functioning. This book is expected to fulfill these requirements by way of highlighting the biodiversity wealth of riverine ecosystem with special emphasis on fishes and river associated or dependent wildlife in the backdrop of the basic ecological and limnological foundations toward ecological functioning of rivers on one hand and also unraveling the causes of eco-degradation and their mitigation on the other. Apart from highlighting the basic ecological concepts, hypotheses, and theories pertaining to freshwater river systems of tropical biogeographic zones, the book will highlight the ongoing environmental perturbations and potential of biodiversity with an emphasis their synergistic effects in ensuring the resistance and resilience of riverine ecosystem functioning based on original research studies conducted during last two decades in the riverine networks of South West Bengal, India. Moreover, the river restoration process in view of ongoing perturbation on the riverine ecosystem mainly because of human activities, and their societal and political implications have also been discussed. Besides, different methodologies in order to unravel the ecological complexity in the riverine environment along with sustainable water and its resources management and conservation have been taken care off. Besides emphasizing the ecological messages for the international community, based on regional synergy among different structural components of a stressed ecosystem, this book aims to fill up the gap in relevant knowledge base from the perspective of the tropical environment of a developing country still encumbered by an array of socio-eco-biological problems.

This socioeconomic development is an integrated, planned, and comprehensive long-term process, the purpose of which is to make the judicious use of water meeting the optimum requirement. The criteria for such optimum use depend on the constraints of socioeconomic growth and environmental management (United Nations 1970). Different steps in environmental management process include the identification of the problems alongside pointing out of their points of origins in order to set up a diagnostic interpretation of the problems and their sources within freshwater ecosystems which are found to impose more harmful impacts among several aquatic inland water ecosystems, than saline and brackish water ecosystems. To undertake strategies for an integrated and holistic environmental and ecological management, development of mass balances based on conservation principles are required to calculate important concentrations of pollutants, as well as to understand important ecological processes such as bioaccumulation and bio-magnification in order to combat the environmental pollution threats on aquatic inland water ecosystems.

Considering all, several aspects are taken into consideration for the sustainable eco-management of rivers for deriving maximum benefits for the human beings in terms of biodiversity resources. Such objectives have necessitated to undertake research studies on the functioning of river systems, eco-assessment of the riverine ecosystem against the pollution stresses, eco-restoration, and eco-rehabilitation of riverine ecosystems. In order to underneath three pillars of sustainable river management (ecology, economy, and sociology), integration on the present knowledge base on **living rivers** about their structures, functioning, and management involving different disciplines is needed as a part of such holistic and long-term river management (Minshall et al. (1983); Minshall et al. (1985); Naiman and Bilby (1998); Welcomme and Winterbourn (1988); Wetzel.R.G. (2001).

1.1 Past and Present Perspectives of Aquatic Ecology

A continuous flow of information had emerged from different case studies, scientific principles, hypotheses, and theories pertaining to aquatic ecology dealing with different dimensions of nature from the qualitative and quantitative approaches. The pioneering works of G.E. Hutchinson (1957) on aquatic ecology has formed most of the foundations of modern ecological studies centering on ecosystems, habitats, population dynamics, and biotic community which have now been the focal theme of most of the applied ecological research of the present era keeping in mind to unearth valuable baseline information on biodiversity, ecological changes and perturbations, chalking out sustainable conservation strategies, etc. Considering and consolidating most of the pertinent researches on aquatic ecology, it is possible to apply the scientific outcomes along with newly derived and established scientific principles and laws for deciphering knowledge on limnetic, marine, and terrestrial biotic communities.

1.2 Water and Rivers

Water, being an essential life sustaining substance, mostly comprises **90%** of living materials and is distributed widely, covering nearly three-fourths of the earth's surface. Water is considered as universal solvent dissolving gases, nutrients, and minerals. Based on the solute concentration of water, it is categorized as freshwater (in rivers, streams, lakes, etc.) and saline water (estuary, sea, etc.). The availability of water from the natural sources within a river basin generally hardly coincide with the growing need water to keep pace with the socioeconomic development and with the constraints of the environment management in the same basin.

Consequently, there is a need for establishing a continuous balance between the demand for human beings and natural supply of water to meet it over time, space, quality, quantity, and energy. This balance is expected to be achieved by establishing and maintaining by the integrated river basin development strategy, which involves a large number of environmentally sound water management and conservation activities. This socioeconomic development is an integrated, planned, and comprehensive long-term process, the purpose of which is to make the judicious use of water meeting the optimum requirement.

The criteria for such optimum use depend on the constraints of socioeconomic growth and environmental management (United Nations 1970). The evolution of the development process of river basins can be summarized into three successive phases within river basins : (**i**) the natural (period I); (**ii**) the developing (period II), and (**iii**) the matured (period III). The objectives, the means, the strategies for the development of a river basin, the complexity of river basin management, and the images of the river basin depend on the stage of river basin development (Mole et al. 2007; David 1976).

1.3 Historical Background of Rivers and Its Uses

More dependence on the construction of dikes as an active flood protection measure became more and more common which put deleterious impact on river ecosystems in several parts of the world. Although drinking water is derived mostly from groundwater wells, surface water is used for drinking too besides its other uses for cleansing and agriculture. Increased discharge of wastewater started in the late nineteenth and twentieth centuries, which was an outcome of rapidly increasing urban populations.

These had necessitated for the development of large-scale but modern water management infrastructures using new technologies in order to cater to the need of the peoples for maintaining healthy life. More emphasis was laid on the roles and contribution of aquatic biodiversity as being an essential component for providing ecosystem service during the middle of the twentieth century where riverine animals and plants were supposed to have played important roles as ecological service providers (Chakraborty 2017). By the mid-1970s, increasing attention in the developed world was being given to water quality management by controlling non-point as well as point sources of pollutant discharges and to water management in metropolitan regions.

In addition, several large-scale engineering and multi-purpose reservoir projects which were previously viewed as the sign of social advancement and technological progress were should be discontinued because of their harmful impacts on the riverine ecology. The current concept pertaining to the functioning of flowing-water or lotic systems helps understanding the life history and distribution of biota of large river ecosystems (Cummins et al. 1984, Minshall 1988, Minshall et al. 1985). Since the mid-**1900s**, the emphasis of researches on rivers started shifting from the enumeration and recording of flora and fauna to describing and quantifying biological production and energy flow within streams.

1.4 Man and the Rivers: Conflicts and Remedies

In many developing countries, human pressure on land and water resources in combination with adverse climatological conditions (rainfall, temperature, and similar meteorological factors) in sensitive surroundings has seriously threatened the river basins and their ecological setup. Severe erosion problems invariably seem to be the outcome of intensification in land use, without proper attention being paid to conservation measures which seem to complicate the river flows of upstream and downstream interactions and impose more complications in solving water and soil conservation and utilization in most of the world's largest river basins.

In industrialized countries, extensive industrialization and urban pressure in general, as well as high-input modern agriculture, may lead to considerable changes in water quality characteristics in urban areas as well as in rural areas. Man has modified rivers since the inception of human civilization. The four river valley civilizations discovered with their relics are Tigris and Euphrates Valleys (Mesopotamia), the Nile River (Egypt), Yellow River (China), and the Indus River (India). In the initial phase, people had to adapt and modify the environment for their survival and alter the river environment.

Modern human civilization had had to undertake activities disrupting the natural balance of the environment such as mining, deforestation, building of roads, agriculture, etc. The exact timing of anthropogenic impact could not be determined definitely as the knowledge of the ecology of river so far accumulated is meager, and based on such information, it is really difficult to make any prediction on the need and mode of utilization of such water by human being; as such, predictions of the long-term ecological effects because of interactions of man with river will not produce any definite results.

However, ongoing onslaughts on rivers in the form of man-made pollution and natural hazards have posed serious threats to the sustainability of riverine resource base during the last one century at an alarming intensity. Alongside floods, drought remains the major threat today leading to economic recession, depopulation, and political instability. In the present time, rapid population growth and increased per capita demand for water especially within the developing countries has resulted acute water scarcity.

In the past, the river developments have caused dramatic ecological impacts, in the form of a loss of habitat diversity, the reduction of species richness, and decline in productivity. However, the modern approach to river development has been founded adhering to the concept of environmental sustainability that incorporates the need to conserve biodiversity. The existing knowledge pertaining to the mutual interdependence of river and human being is still very limited.

Various conflicts over water and their management in terms of economic sanctions and the use of non-formal institutions may be of considerable importance both for avoiding and for the handling of conflicts. Conflict management has been seen to become complicated by the development of a number of socioeconomic problems mostly due to the political interference in the administrative sectors underlining the conflicts or hamper a rational management. Large-scale water regulation projects, such as dams, may create conflicts between proponents for a utilization of the regulation capacity for hydropower generation policies, etc. and those favoring the use of the regulating capacity for agricultural purposes.

Inter-basin transfer of water or long-distance transfer of energy from hydropower plants will, e.g., transcend the division of entities based on the water divide. Administration of the geographical regions of basins is in the contemporary socioeconomic-political setting in industrialized countries influenced by urban oriented policies and analyses. Development of regional thinking in developing countries is obviously to a large degree based on a realization of the close interrelations between land and water resources in a river basin perspective.

A systems approach hardly solves river basin management because of urban pressure and overall population increase. As rural development involves the coordinated water and land utilization measures for the conservation and management with respect to sectoral demand and areal extension, the intensification of land use, and related ecological changes, is quite often a result of urban pressure to determine and orient the strategies to meet the short term and local demands.

1.5 Ecological Values: Origin and Conflicts in the Perspective of River Ecosystem

The ecological values are centered mainly around the diversity and distribution of biodiversity across the different zones and strata of rivers in tune with the changing ecological conditions which are reflected by their roles in determining the food chains and food web dynamics, trophic interactions, and the intensity of biological production of the rivers.

The economic value of river serves as fundamental criteria for the all-round growth and development of countries including different biogeographic regions by way of the production of hydroelectricity and providing profuse quantity of water for the domestic, agriculture, mining, and industrial activities. The non-disruption and sustenance of ecosystem services of the river ecosystems have appeared to render valuable contribution toward sustainable conservation and recovery. Human activities have affected rivers of the globe and produced changes in morphometry, volume and depth of water, water flow regime, and water quality because of the massive abstraction of river water for the use in irrigation for agriculture, industries, domestic activities, constructing of reservoirs, hydroelectric power plants, and other built structures, steady and continuous changes in land use and exploitation of the aquatic biota which all independently or in combined manners disrupt the hydrological cycles. The rivers and their associated floodplains support plant and animal life, in the form of planktons, benthos, hydrophytes and water grasses, different shell- and fin fish, water amphibians, reptiles, birds, and mammals.

All these biodiversity components that live near the origin of rivers (upstream) may be different from living things farther downstream. The river begins high in the Rocky Mountain forests and ends as a stream, estuaries to the sea. Two main rivers of India, viz., the Brahmaputra and the Ganges, differ from one another in respect of their origin, the courses of their movement and other ecological properties. The Brahmaputra River after having its origin on the Tibetan Plateau in China passes through the Himalayan Mountains and eastern India before joining the Ganges River in Bangladesh. The river Ganges of India being a sacred river originating in the western Himalaya and flowing through several states of India before ending to the Bay of Bengal, in the extreme eastern part of the country. India's rivers have endured difficult turmoil ecological conditions due to pollution by the release of industrial, agriculture, and domestic wastes, shipping activities, and everincreasing demands of large human population from the rivers.

1.6 Biodiversity of Rivers and Their Interactions with Environmental Condition

The diversified forms of floral components (taxonomic diversity – varied forms of species and morpho-ecological diversity – floating, submerged, riparian, etc.) in the river basins and channels displaying seasonality in respect of their growth and biomass development contribute significantly to channel roughness, reducing current velocity, raising the water level, increasing hydraulic resistance, etc. (Westlake and Dawson 1982, Watson 1987; Beven and Carling 1992). The impacts imposed by the localized flow variations on the substratum also result in a diversity of microhabitats which enable different benthic fauna to diversify undergoing adaptation to the newly developing habitats (Armitage 1995; Newall 1995). Reduced flow in the local area is often utilized by the river invertebrates (Friberg et al. 1994) and fish larvae (Mills 1991) as refugia in adverse flow conditions.

Getting support from the macrophytes stands as shelter, proportionately fewer fish are lost in floods from hydraulically complex stream sections compared with simpler channels (Pearsons et al. 1992).

Alterations in the hydraulics and habitat area by the changing geo-hydrological condition and physical structure of rivers trigger spontaneous responses from the invertebrate communities; for example, the trapping of leaf litter was found to exert a significant influence upon the local abundance of shredders (Dobson et al. 1992). Plant-based habitats through an interplay of several structural components contribute profusely in enhancing community structure (Friberg et al. 1994). Invertebrate distribution in rivers is primarily related to oviposition sites, migration, and drift (Ladle and Ladle 1992). Emergent stems may be important sites selected for oviposition by some species of insects (Wolf and Waltz 1988; Gibbons and Pain 1992).

1.7 Factors Making Floodplains as a Reservoir of Biodiversity

Floodplain rivers representing the disturbance-dominated ecotonic ecosystems are characterized by high levels of habitat diversity and biota adapted to exploit the spatiotemporal heterogeneity. Shifting mosaic of habitat patches are created by the fluvial action of flooding and channel migration across the riverine landscape enjoying the connectivity and succession which in turn lead to the high biodiversity.

Ecotones and connectivity are interrelated structural and functional attributes, respectively, of heterogeneous environments which governs the growth and propagation of biodiversity. Floodplains ecotones along with the naturally flowing rivers representing one of the biologically productive ecosystems of the world due to their unique ecodynamics associated with spatial and temporal complexity, controls several ecological processes like nitrogen fixation, nutrient exchanges etc. and also structure species richness patterns (Naiman et al. 1988; Amoros et al. 1996).

Connectivity from a purely biological perspective refers to gene flow between metapopulations and the extent to which ecotones alter dispersal, movement, and migration. All of these eco-biological processes in turn determine the extent of interplay among nutrients, organic matter, exchange of energy between the ecotones with the adjacent ecozones. Hydrological connectivity, the transfer of water between the river channels and the floodplains and between surface and subsurface compartments, has major implications for biodiversity enrichment and in the structuring of succession patterns.

1.8 Fish, Riverine Habitats, and Flood Pulses

It appears to be difficult to explain the intimate relationship of fish with flowing water and also to understand the steady responses of the fishes to dynamisms and oscillation of multi-scale habitat variables of large floodplain rivers due their spatial and temporal complexities. Unlike low-order rivers where relatively simple geomorphologic and hydraulic variables are useful to define habitat requirements. The survival strategies of fishes by their acquisition of physiological and morphological adaptations, trophic position, migratory behavior, reproductive patterns, parental cares and nurturing of juveniles (spawns and larvae), growth, recruitment, etc. to take advantage of the complexity embedded with the riverine ecosystem. Besides, hydro-geomorphic guiding principle on the plausible effects of the flood pulse was used to propose general seasonal and spatial patterns in the transport, transformation, production, and redistribution of bio-organic materials within a river corridor. This is possible by integrating the functional and structural linkages among different fluvial components such as floodplains and main and secondary channels. Biodiversity conservation, particularly for the fluvial-dependent fishes having complex life histories and extensive place-searching movement patterns, allows them to adjust with the changing ecological conditions of the river machine. The conventional concepts of habitat elucidates a broader perspective to recognize the potential and ability of fish to manifest two essential behaviors: **(1)** place-specific behaviors where fishes spend most of their time residing within microhabitats and **(2)** place-searching behaviors for fishes that spend a substantial part of their time using in search of new place as their prospective suitable habitat that allows fish to exploit large river processes. General hydro-geomorphic guiding principle based on the baseline information regarding the plausible effects of the flood pulse to ensure the transport, transformation, production, and redistribution of materials within a river corridor in the seasonal and spatial scales enable to chalk out suitable fishery management strategies. These effects integrate functional and structural linkages among different fluvial components such as floodplains and main and secondary channels. All of these knowledge bases pertaining to the tremendous diversity and abundance of life in large floodplain rivers act as prerequisite for undertaking proper restoration and conservation measures.

The impact of flood pulse on river basins and subsequent ecological responses in respect of biogeochemical cycles, trophic, dynamics, transport of nutrients, the progression of rising water levels, along with high water and fall of the flood pulse creates a sequence of complex, and large-scale hydraulic patterns over an annual cycle. The resultant hydro-geomorphic forces transport nutrients, accelerate the erosion process, transport and deposit the sediments, enhance the turbidity, and create a favorable ecological conditions for chemical and biological processes (litter decomposition, primary productivity etc.). With the receding of water during dry spells, floodplain dissolved organic matters, particulate organic carbon and floating plant biomass, nutrients, and energy of floodplain are exported to main channel and trigger food web compartments and enhance ecosystem productivity by the biotic communities (Junk et al. 1989; Welcome 1979, 1985; Lamberts and Koponen 2008).

1.9 Ecological Succession of Floral and Faunal Components

Successional processes structured by flooding and channel migration of motile fauna are responsible for much of the spatiotemporal habitat heterogeneity promoting the growth and propagation of different biodiversity components (riparian flora coupled with their associated fauna) of riverine floodplains enjoying different stages of succession which in turn maintain a diversity of lotic, semi-lotic, and lentic water bodies on the floodplain and create a diverse mosaic of riparian vegetation across the riverine landscape. Massive erosion due to deforestation and initiation of primary succession start on point bars of alluvium deposited as annual increments on the river beds. Various forms of river regulation, including modification of natural flow dynamics, dredging, channel straightening, bank stabilization, and construction of artificial levees, have altered successional trajectories and disrupted connectivity between ecological units of the floodplain and other aquifer complex in many of the world's rivers. River regulation disrupts the natural disturbance regimes that maintain a diversity of successional stages and high levels of connectivity across the riverine landscape, resulting in a loss of habitat heterogeneity and biodiversity.

1.10 Eco-management of Rivers: Roles of Ecological Studies

Out of so many ecosystems of the world, freshwater ecosystems play a decisive role in the biosphere, as human beings along with many other living organisms are primarily dependent on freshwater which justifies interest in the assessment ecological health of this type of ecosystem in view of the ongoing threats because of varied form of direct or indirect human activities or disturbances. Eco-management with an aim at undertaking sustainable restoration of river ecosystems are based on an understanding of the relations between physical, chemical, and biological processes at varying time scales.

All these eco-biological processes have been accelerated by different human activities and ultimately result to develop unstable flow patterns coupled with modified biological structure and function of the biological assemblages within and even outside the main riverine flows. Such ecological efforts to tackle the problems of a multitude of disturbances which include the social perspectives of river management in the light of historical change in the bioresource-based management of the floodplains, pollution, and toxic contamination in respect of ecological health, water quality, biodiversity loss, etc. in order to draw the relationship between river management and economic growth in urban regions.

1.11 Biodiversity as an Ecological Concept: Hierarchical Framework

A continuous flow of information have emerged from different case studies, scientific principles, hypotheses, and theories pertaining to aquatic ecology dealing with different dimensions of nature from the qualitative and quantitative approaches. The pioneering works of G.E. Hutchinson (1957) on aquatic ecology has developed most of the foundations of modern ecological studies centering on ecosystems, habitats, population dynamics, and biotic community which are now focused, expanded, and applied in undertaking present ecological research keeping in mind to unearth valuable baseline information on biodiversity, ecological changes and perturbations, chalking out sustainable conservation strategies, etc. Considering and consolidating most of the pertinent researches on aquatic ecology, it is possible to apply the scientific outcomes along with newly derived and established scientific principles and laws for deciphering knowledge on limnetic, marine, and terrestrial biotic communities. Biodiversity being an ecological concept forms a bigger canvas than species diversity and genetic diversity and includes functional (process) diversity in the sense as habitat diversity as integral part within biodiversity.

The three primary ecosystem attributes such as composition, structure, and function are being used to develop a hierarchical framework of biodiversity across four levels of organization. Rivers and their floodplain are especially amenable to a hierarchical approach for examining biodiversity, and to have a proper eco-assessment of the contributory factors, determining the structure and diversity patterns of local species assemblages requires knowledge of processes that determine species richness at the regional level and the rates of spatial turnover of species. Gamma(γ) diversity, the total number of species in a region, is a function of the number of species per habitat, which is designated as alpha(a) diversity, and the number of habitats (habitat diversity), along with the turnover of species between habitats, is named as beta diversity(**ß**). Beta(**ß**) diversity may be calculated simply as the inverse of the mean number of habitats occupied by each species occurring in the region (mean number of habitats per species).

Consideration of beta (**ß**) diversity enables one to distinguish between the separate contributions of habitat heterogeneity and species' characteristics (habitat breadth) to the total species diversity of a region (Ricklefs and Schluter 1993). The "**region**" under consideration in the gamma diversity (⍰) denotes different scales (viz., catchment, reach, pools, riffles, floodplain, floodplain transect, etc.), thereby separating habitat breadth from habitat heterogeneity at different hierarchical levels. In some respects, beta (**ß**) diversity being a measure of the degree of connectivity between habitats refers to the turnover of species between habitats and provides a new perspective for understanding biodiversity of rivers and floodplains and the prospective influence of river regulation on biodiversity patterns. Applications of the concept of biodiversity to floodplain river ecosystems were addressed by De'camps and Tabacchi (1994) based on the initial proposal of Ward and Stanford (1983a, b, c) and subsequent corroborations by Connell (1978) with the intermediate disturbance hypothesis and also by McCormick and Stevenson (1989) mainly citing the case studies pertaining on foraging behavior of snails on algae. Besides, such proposition were verified by Hemphill and Cooper 1983; McAuliffe 1984; and Hemphill 1991 on their studies on community interactions among insects, by Minckley and Meffe 1987 on competing species of stream fish and by Tabacchi et al. 1996 on their studidiversity patterns of river based plantses on the (Tabacchi et al. 1996),. rendered strength to support the applicability of this concept to lotic ecosystems. Hildrew and Townsend (1987) put forward their views in support of the application of dynamic equilibrium model to explain the mode and intensity of impacts of the disturbance and productivity on the regimes structure feeding guilds and the predominance of sessile versus mobile species.

1.12 River Ecosystem: Habitat and Biodiversity

Habitat diversity, which increases with stream sinuosity, directly influences the biological diversity within rivers and streams. The concept that the stable ecological condition promotes diversity and availability of habitats is given priority in the restoration activities of river ecosystem. Less disturbed ecological conditions provide less physical diversity of habitat triggering less scope for biodiversity, while more disturbed ecology promote more habitat heterogeneity resulting in more biologically rich habitats. These are evident from the facts that a uniform and homogenous sand bed in a river or stream provides less diversity of habitat than a heterogeneous mixture of habitats such as bed with debris, boulder, peddles, and sands, in sequences at step-pool, pool-riffle sequences, or other such types of habitats.

Both terrestrial ecosystem (mostly on plants community) and aquatic ecosystems (hydrophytes, plankta, benthos, nektons, and aquatic wild higher chordates) in a concerted manner put their impact to determine the biological community of a river ecosystem. The high primary productivity and biomass of riparian areas as the major food sources are very different from the adjoining terrestrial area. The river basins with ecological corridors provide water, nutrients, shade, and avenues for evapotranspiration and thereby ameliorate the temperature and moisture extremes of uplands.

Nearly all wild animals (many amphibians, reptiles, birds, and mammals) inhabit primarily in river corridors and riparian habitats get comfortable assurance for their food and suitable shelter. Aquatic plants of rivers and streams usually include attached to permanent stream substrates and macrophytes including floating plants, such as *Eichhornia crassipes*; submerged plants, such as *Potamogeton* and emergent plants, such as *Phragmites communis trirn*.

These plants through their profuse growth and biomass development by primary productivity provide food, shelter, and multiple breeding ground to several faunal components, which in turn by their behavioral activities help decontaminating the river water. Submerged macrophytes include species like Potamogeton, floating plants species *Lemna minor L.*, and emergent plants species *Phragmites communis trirn* (reed). Rooted aquatic vegetation is grown up based on the suitability of substrates where intensity of water currents do not scour the stream bottom and dislodge the settling seeds or saplings.

Luxurant growth of large vascular plants occur in some ecozones having clarity of water, stable substrates with high nutrients, slower current of water, and profuse availability of sunlight. Benthic invertebrates (crabs, crayfish, gastropods, oligochaetes, etc.) also collectively contribute to sustain the aquatic ecosystem by acting as ecological engineers by reshuffling the sediments, acting as macro-degradator facilitating the breakdown of organic materials, converting leaf litter into detritus, producing millions of larvae as meroplanka as the food of fauna for higher trophic levels, and with similar activities (Chakraborty 2017), Some other benthic invertebrates act as filter feeders by filtering huge amount of turbid water by extracting smaller organic materials from the overlying water, and they are known as filterers (larvae of caddisfly, blackfly, stonefly, etc.; nymphs of mayfly; bivalves).

Similarly, some benthic fauna designated as scrapers scrap materials off the surfaces of semi- decomposed logs, boulders, gravels, and cobles (snails, bivalves, nymphs and larvae of some aquatic insects, etc.). Some other benthos, known as collectors, feed on deposited organic substances on the substrate (dipteran larvae, mayfly nymphs, etc.), while other macro-invertebrates, as known as predators, predate on smaller zooplankton and benthos such as dragonfly.

1.13 India and Its Riverine Biodiversity Wealth

India, being the second most populous country of the world, is gifted with some uniqueness in respect of her geological history, highly diverse physiography, monsoon-dependent climate with extreme temporal and spatial variability, and high biodiversity. Being also a megadiversity country having four different biodiversity hot spots, she is also endowed with diverse freshwater aquatic bodies in the form of rivers, streams, floodplains, dams, lakes, springs,, bills, ponds, and different other forms of wetlands. In India **14** major, **44** medium and hundreds of minor river systems form extensive riverine networks of which majority are perennial rivers with large seasonal variation in their flows.

The several gigantic rivers in India such as the Ganges, Jamuna, Indus, and Brahmaputra, have their origins from the Himalaya, and other rivers like Krishna, Kaveri and Godabari mostly in the southern India have their different origins from the hilly tracts of Western Ghat mountain range. All of those rivers transport annually a heavy load of sediments and deposit the same in their different stretches. Investigations of lotic aquatic biodiversity have gained tremendous momentum since the early nineteenth century, and rising demand for water (potable and commercial) and fish has prompted the environmental planners the need for managing the water quality (Brij Gopal and Zutshi 1998).

Earlier records of various research studies of aquatic biota in India have revealed some publications depicting extensive research-based surveys of aquatic fauna, mainly from the freshwater habitats during the early nineteenth century when the country is under the British rule (Hamilton 1822; Day 1873, 1878). It is interesting to note that Earnest Haeckel, who first coined the term ecology, had published research papers on fish fauna from Kashmir Valley as early as **1838** (Das and Subla 1963). A comprehensive documentation on different aspects of the eco-biology of aquatic fauna during pre- and post-independence era of India was edited by Gopal (1997). Under the leadership of Annandale, the first Director of Zoological Survey of India, several faunal surveys from different aquatic habitats were conducted involving many native Indian scientists working in the Indian Museum and Calcutta University (Annadale et al. 1921). Botanists did not fail much in their attention to habitats as the Botanical Survey of India had been established much earlier (Hooker 1872–97).

The initial couple of decades after independence of India in the year 1947 represented a period of continuity with the pre-independence studies with rapid expansion into unexplored areas. The investigations of fishes diversified into areas such as food and feeding behavior, reproductive biology, physiology, ecology, cytology, systematics, and morphotaxonomy.

1.14 Diversity of Wildlife and Their Roles Toward Riverine Ecosystem

The Indian subcontinent supports rich biodiversity in different types of forests (tropical dry and moist deciduous, evergreen, coniferous, and mangroves) and in other ecosystems including the floodplains of the Indus, Ganges, and Brahmaputra rivers which have been created millions of years ago through several geological events. The northern part of India with snowcapped Himalayan supports the lives of so many rare and elusive faunal components such as snow leopard, musk deer, wild goat, yaks, and different types of birds. The desert ecosystem in the western India harbors a variety of thorny plants, scrubby and grassy landscapes, and interesting animals like wild ass and Indian lion which are found nowhere else on earth. Toward the east, and north east with the neighboring countries like Bangladesh, Nepal Bhutan, and Burma, with cloud forests and swamps shelter wildlife forms ranging from tigers, elephants, rhinoceros, gibbons, hispid hares, assamese macaque, etc. The Western Ghats, an ancient chain of hills running from north to south, fringing the western coast of India, still support the very existence of the Asia's densest rain forests. The scrub and grasslands of the Deccan Plateau are happy homes for many primate species along with the presence of leopards, elephants, and a myriad of avifauna. Besides, the gigantic presence of mangroves with its several charismatic species including the royal Bengal tiger in the east coast and the finest coral formations all along the peninsula's coastline along with the Andaman and Nicobar islands have added elegance of the wild wealth of India. Interestingly due to the previous geological events, the leopards were able to colonize the neighboring country, the Sri Lanka, while tigers never reached to that island indicating that the island was separated from Asian mainland before the spread of the tiger from Central Asia to the north Indian plains.

In recent years, the Indian government has taken a more progressive attitude toward the protection of wild-animals by enacting Wildlife Protection (Act) 1972, and as a policy matter, the respective government departments, such as Ministry of Environment and Forests, have come down hard on wildlife traders, poachers, and exploiters to combat the problems of wildlife crimes. Consequently, India is probably the last hope of the survival for the one-horned rhinoceros, the great Indian Bustard, the vulture, the gharial, and a hoard of other highly endangered species, many endemic to the subcontinent.

1.15 Ecological Health of Rivers: Aquatic Invertebrates as Biological Indicators

Ecological health of river does not indicate for higher recreational avenues but focus more on the healthier landscape which in turn make the human beings healthier both physically and mentally. Complete and comprehensive assessments of river health by using pronounced structural components such as water quality parameters, species composition, and diversity of aquatic organisms along with their functional contributions accelerating the rates of organic matter decomposition and ecosystem metabolism (gross primary productivity, development of plants biomass, ecosystem respiration, community composition of macro- invertebrates, algae, or microbes) have become an established eco-monitoring and eco-management tool. However, natural functional processes of river ecosystems (differential flow patterns, natural deposition, and biotic utilization of materials carried by water, trophic interactions, energy flows, etc.) are affected by both natural and human-induced variation in a wide range of environmental factors. River health is difficult to assess (Norris and Thoms 1999), mainly because of the lack of the reference condition of the rivers and streams which are subjected to long-term anthropogenic disturbances.

1.16 Biological Integrity vs Ecological Integrity: Assessment of River Health and Ecological Sustainability

Integrity implies an unimpaired condition, or the quality or state of being complete or undivided. The terms like ecological integrity or biological integrity are often used in the ecological subsystem as either concepts competing with ecosystem health or as synonyms for ecosystem health (Callicot et al. 1999). Biological integrity is defined as **"the ability to support and maintain a balanced, integrated, adaptive biological system having the full range of elements (genes, species, and assemblages) and processes (mutation, demography, biotic interactions, nutrient and energy dynamics, and metapopulation processes) expected in the natural habitat of a region"** (Karr 1996). Inherent in this definition are the assumptions that (**1**) living systems act over a variety of scales from individuals to landscapes; (**2**) a fully functioning living system includes items one can count (elements of biodiversity) plus processes that generate and maintain them; and (**3**) living systems are embedded in dynamic evolutionary and biogeographical contexts that influence and are influenced by their physical and chemical environments.

Environmental change has always been a reality, and it is continuous. Global environmental change is driven by wind and water, geologic activity, astronomical events, and the outcome of the continuous interactions among biodiversity components (microorganisms, plants, and animals). Human influences of human beings on environment are not only massive, incessant, and global but also result positive, neutral, or negative changes in the natural fabrics of the prevailing environmental setups. The challenge faced by the conservation biologists and environmental scientists in explaining living systems experiencing the ongoing human-mediated perturbations is to detect and interpret the resultant alterations, to distinguish among its causes, and to understand and interpreting its consequences, In order to take up and overcome the challenges for achieving success from the ecologically sustainable water management, human civilization has to design and implement a water management program that stores and diverts water for human purposes in such a manner without causing eco-degradation. This is thought to be possible by maintaining a balance between the limit of the withdrawal of total amount of water from a river and also a limit in the degree to which the shape of a river's natural flow patterns can be altered. This is required for the purpose of holding the natural ecological integrity of the affected ecosystems in intact condition in such a way so that the loss of native species can be prevented alongside preserving precious ecosystem products and services for the benefits of human society. Therefore ecologically sustainable water management can be admitted as an iterative process in which both human water demands and ecosystem requirements are defined, addressed, refined, and modified to meet human and ecosystem sustainability.

The term and concept of the sustainability' appears to be the most comprehensive concept in the realm of environmental management and politics which assumes as an ethical precept, being more a concept of prediction instead of being definitional (Costanza and Patten 1995). In accordance with the Brundtland Commission report **Our Common Future** (World Commission on Environment and Development 1987) three fundamental components of sustainable development (environmental, social and economical) have emphasized mostly on to environmental protection, economic growth, and social equity which are to be balanced and considered together to achieve the sustainability. Applying the concept of sustainability to river systems implies that river management with the prime objectives of ensuring successful economic and social functions (Leuven et al. 2000).

Effective and successful monitoring in order to report as well as to assign proper ecological status has become a crucial component of natural-resource management. The concept of ecological integrity has been enunciated mainly because of the pro-environmental realization to ensure complete protection to indigenous diversity (genes, populations, species, communities, ecosystems) along with the ecological patterns and processes that create and support that diversity. Ecosystem integrity is defined as the system's capacity to maintain structure and functions using processes and elements characteristic for its eco-region (Dorren et al. 2004). Presently, ecological integrity is being considered as a holistic concept and framework that focuses on conserving native biodiversity, using the natural or historic range of variation as a reference point, and promoting resilience which represents the ability of the ecosystem while undergoing undesirable changes to still resist the disturbances and also to retain the function, structure, identity, and feedbacks (Walker 2010, Keenleyside et al. 2012). Ecological integrity emphasizes the importance of ecological processes such as natural disturbances regimes that provide structure and functions on which the full complement of species in an ecosystem depends (Angermeier and Karr 1994, Andreasen et al. 2001).

Although the conservation strategy at the community level has been found to be more effective than species-level conservation, however, community level conservation has become more difficult as more natural areas are to be covered which renders more difficulty in analyzing the complicated nature of a community. Ecological integrity is measured as the degree to which a diverse community of native organisms is maintained and is used as a proxy for ecological resilience, intended as the capacity of an ecosystem to adapt in the face of stressors while maintaining the functions of interest. Biological integrity is defined as the maintenance of the community structure and functions characteristic of a particular locale or deemed satisfactory to society (Cairns 1977).

The river health become implicit in river integrity in the process of eco-restoration maintaining the chemical, physical, and biological integrity where integrity is conceptualized as the maintenance of natural structure and function of ecosystems (Karr 1999). Different biotic components of rivers and streams, especially the non-chordate fauna living in the small-scale habitats, act as indicators of the ecological health of rivers and streams because of their sensitivity to even slight ecological changes (water pollution, erosion load on water, deterioration of water quality, etc.) in their environment. Aquatic invertebrates live in small-scale habitats; therefore they are much more vulnerable to anthropogenic disturbances (LaBonte et al. 2001). Shredders and scrapers are considered to be more sensitive to environmental disturbances because they exhibit the highest level of feeding specialization, whereas filter feeders and gathering collectors are more tolerant to disturbances because they exhibit generalist feeding habits (Barbour et al. 1999). Besides, invertebrates' faunal components of rivers or streams help enhancing stream nutrient cycling through their feeding strategies, but also support other biotic offering themselves as foods. The integrity of invertebrate communities is profusely dependent upon the structural integrity of the stream and the processes associated with the physical habitat.

The Water Framework Directive (**WFD**) establishes that ecological status must be classified into five quality classes (high, good, moderate, poor, and bad) by means of biological indicators. In this context, through research studies several biotic indices based on the sensitivity responses of macro-invertebrates have ensured a proper classificatory scheme of the ecological status of rivers and streams. Besides, difficulty lies in assessing important spatial and temporal variability in solute concentrations of temporary streams as regards both biological and physicochemical quality. The diverse macro-invertebrate communities within the streams enjoying wide variability in hydrology conditions (low surface flow and spatial intermittency) withstand the effects of differences in advection, water residence time, biological community structure, sediment–water interactions, or environment redox conditions through stream channels and exhibit their responses. Besides, all these factors influence the rates of the biogeochemical processes involved in the nutrients cycles which are instrumental in triggering different biogeochemical process rates and reactions within the rivers. Changing of stream-channel environmental conditions over time as flow discharge changes increases the variability of physicochemical quality on the temporal scale.

1.17 Three Main Global Problems: River Water Management Perspectives

The world suffers at present from a number of severe global problems related to the natural environment which cause a large-scale deterioration of the natural resource base for present and future generations. In order to identify, assess, and develop a general framework for developing an ecologically sustainable water management program, drawing upon examples from the rivers systems of different parts of the globe with regard to the intensity, extent, diversity, and trend of ecological degradation and other related ecological problems with their causes and effects, the following points have been identified: (**1**) the absence of a clear policy for decision-making at different levels in the hierarchy, based on a recognition that natural systems obey laws of their own; (**2**) lack of eco-friendly development as it is often understood as social, economical, and political phenomenon, neglecting the significance of natural environment with its resource base; and (**3**) large-scale deterioration of water quality all over the world.

In industrialized countries, the pollution of rivers passing through urban areas is considered a large problem, and massive capital investments have gone into treatment plants and other measures to reduce the negative impact of point outlets on fishing and other beneficial uses of the river as a resource. As these water quality problems have been addressed and counteracted, new generations of quality problems have developed as a result of modern agriculture supported by high level use of fertilizers, herbicides, and insecticides. Also, airborne pollutants are causing serious water quality problems including acidification problems in temperate areas with poor soil buffering capacity.

1.18 Strategy for Coordinated Land and Water Conservation: Synthesis and Ecological Outcomes

The very existence of human activities has been closely connected with land and water for harvesting basic ingredients for the maintenance of life and also to increase the socioeconomic benefits from these resources, but are at the same time impeded deleterious impacts on the environment from such interventions.

The rivers and their floodplains within the river basin forms a natural physical boundary to test the interdependence between land and water, and the development of water resources is meant to better adapt and ensure water availability to meet the needs of water in time and space. The bondage in between land and water hovering over twofold objectives: (**1**) land use is to a large extent water dependent; and (**2**) water use may be disturbed by water-impacting land use. The steady and continuous interdependence and interaction in between land and water act as prerequisite for appropriate environmental management instead of treating land and water as separate issues in the planning, and execution for the water conservation with sustained productivity of natural life-support systems giving due importance on socioeconomic political in mind would call for a balance between political objectives and the function of such natural systems.

1.19 Pollution of Rivers: Water Quality Degradation Within and Outside River Flows

Ever-increasing population explosion coupled with unplanned urbanization and industrialization, especially in the developing country like India with the emission, release, and dumping of gaseous, liquid, and solid wastes, respectively, have considerably polluted to a frightening degree, the pollution of the water, air, and land resulting to threaten more **31, 000** large and highly evolved species with extinction (**34%** conifers; **25 5** mammals; **14%** birds; **41%** amphibians; **30%** marine fishes, sharks, and rays; **33%** reef corals; and **27%** selected crustacean) with an average of **27%** of all assessed species in the world. The aquatic ecosystem, especially the rivers and lakes, have been under more pollution threats. Most of the waste released from the industries and municipal sewage into the riverine water contribute for an enormous proliferation in the total bacterial colonies that act upon organic substances present in the water to extract their foods and nutrients in the process of decomposition utilizing the dissolved of oxygen of water, making the entire water bodies non-suitable for the fish, and other aquatic animals and plants to survive.

The pollution of rivers (releasing of fertilizers, herbicides, and insecticides used in modern technology-based agriculture; industrial and municipal discharges; dumping of wastes; development thermal and hydroelectric power plants; etc.) traversing through urban areas has become a serious threat to the human civilization mostly due to the deterioration of water quality and there by imposing deleterious impact on fishing and other beneficial uses of the river as a resource.

In addition, atmospheric pollutants have been rendering serious water quality problems including acidification, disrupting soil buffering, etc. To ensure sustainable conservation and optimal management of the river ecosystem have appeared to be one of the greatest challenges that ever faced by facing mankind. A sound conservation and management policy by overcoming the problems pertaining to of maintaining of fundamental and mutually interacting life support systems and without any without inviting disturbances for conserving land and water along with their biotic components, alongside combating the challenges for abating acute problems of poverty, increasing population pressures and land degradation Systems analysis being a modern tool in the analysis of systems of great complex ecological system emphasizing purely on ecologic perspective taking into consideration as the land and water systems as ecological units holds great promise in the realm of environmental management.

Such ecosystem approach is considered as a means not only to guide management of complex ecological systems but also to solve problems due to misuse and mismanagement of the environment, putting more emphasis on the understanding of the nature and influences of various interacting forces in response to environmental manipulations by man.

1.20 The River Discontinuum: Human Alteration of Large River Ecosystems

Construction of dams on the flowing rivers adversely affect the river ecosystem by changing flow patterns, disrupting thermal regimes and sediment transport, disconnecting river corridors, and modifying aquatic and terrestrial habitats (Ward and Stanford 1983a, b, c, Ligon et al. 1995, Poff et al. 1997). Although the removal of dams has been considered as an important method for the river restoration, dams can also provide valuable socioeconomic goods and services, including hydropower, flood control, and recreation which has necessitated to make a balance sheet on the benefits and harms in the river re-habilitation efforts with the continued use of dams. Research information have established the facts that changes in the dam operations can improve the ecological integrity of rivers by achieving and maintaining a better balance between human needs for water and ecosystem resilience. In such context, it is pertinent to pay importance on the perception and attitudes of human beings toward the mode of uses of water resources and to find out new avenues to protect the river ecological systems by consolidating the potential of human creativity in finding ways to use both water and land sustainably and also to impose and maintain good governance of peoples and resources striking a balance between the demand and supply.

Humans vastly reduce the capacity of river ecosystems to sustain natural biodiversity and bioproduction by severing or compromising the dynamic interactive pathways of the river continuum. The indigenous or native biota of rivers display life history traits locally by adapting to the new range of ecological parameters that allow populations to survive within a certain range of environmental variation that characterizes a particular river. Recolonization of the biota take place in the extirpated areas over time by overcoming environmental constraints mainly by undergoing immigration of suitably adapted populations. However, rapid and drastic human-mediated environmental changes severely exceed the ability of biota to adapt with the newly developed undesirable state of environment.

The prevailing interactive pathways of the river continuum are disrupted because of unwanted human intervention pushing the native biodiversity and bioproduction at declining state. Pervasive human perturbations that dissociate important ecological processes from linking of ecosystem components with strong bondages in large river basins can be summarized into three broad categories:

1. Different forms of water pollution are interactive with stream regulation effects in most catchments.
2. Eco-biomanipulation of food web by harvest, stocking, and exotic invasions.

3. Modification of water, temperature, and materials flux due to the diversions of water by developing dams, hydroelectric projects, and alteration of human land use which independently or in a cumulative manner creates and dumps direct and diffuse inputs of waterborne wastes from the catchment (Hynes 1966; Warren 1971), accelerates erosion and sediment loading due to deforestation and road building (Waters 1995), disrupts proper flux rates of materials in rivers (eutrophication, acidification), and jeopardizes riverine food chains–food webs dynamics by toxic effects.
4. Nonjudicious harvesting of commercially important fishes and other aquatic biota; the intentional and accidental introduction of non-native species accelerates strong negative interactions among ecosystem components resulting to disrupting to food webs dynamics by way of biomass and bioproduction shifts, changes in the species composition, replacements of species, and related trophic functioning (Mooney 1986).
5. Alteration of flow regimes and associated blocking of connectivity in the three spatial dimensions of riverine ecosystems are being reflected as the most strikingly pervasive influence of humans on river landscapes worldwide (Dynesius and Nilsson 1994).

1.21 Land Use and Ecological Corridors: Interaction Among Biodiversity Components and Eco-restoration

With a river as an ecosystem with several interacting structural components, both living and nonliving having numerous connections pose challenge to the environmental managers for their successful restoration, even though adhering strictly to all those ecological principles. Certain topographic settings along with periodic, dramatic changes in hydrology because of the seasonal impacts of meteorological factors also play decisive roles in the restoration process.

The vegetational growth, diversity, and assemblages coupling with detritus production process along the riverine course govern the water quality and associated biodiversity components through balanced interactions between terrestrial and aquatic systems and also result the mobilization and conservation of nutrients in complex patterns. The primary damaging roles of varied form of land uses such as agriculture, deforestation, development of grazing fields of the livestock, altered flow patterns of water, differential deposition of sediment, and nutrients cycling cause the changes in the species composition, characteristics, and distribution of vegetation.

As the fish and wildlife are intimately dependent on the riparian vegetation, the fragmentation of the erstwhile native cover types has had a negative impact on these two major biodiversity components, i.e., wildlife and fish, which need large areas of having preferred vegetation. In some riverine tracts, small fractures in the continuity of corridors hamper animal movement and thereby impose negative impact on the natural ecological setup of a stream or river which permit it to host certain aquatic species.

Narrow stream corridors, considered as essentially edge habitat help flourishing of generalist species, parasites and predators, and whereas corridors after being fragmented to develop barriers, prohibit animal movement, and thereby disrupt the integrity of regional animal assemblages (Knopf et al. 1988). At the development phase of planning for restoration of degraded riparian areas, the preexisting ecological states of nearby habitats are given emphasis. It has been observed that non-riparian birds prefer to use the edges of riparian habitats, whereas the smaller riparian birds only undertake breeding activities within the riparian area unlike the larger species who often forage in nearby areas (Carothers et al. 1974).

Considering such findings, it can be postulated that significantly altered ecosystem, especially at upstream, for example, a dam or any other water diversion project, may not ensure possible eco-restoration of eco-degraded ecosystem to its natural, perfect condition.

1.22 Ecosystem Flow Requirements: Societal Perception

In order achieve ecological sustainability in water management, the demand of the hour is to make a compromise in between harvesting of water-based resources to meet human needs and the simultaneous maintenance of the freshwater ecosystems. There have been mounting pressure from different sectors of society in the face of experiencing increasing confrontation because of the results of a number of side effects generated in course of historical water management toward achieving ecological sustainability.

The least flexibility of the societal perception in respect of financial expense, technological complications, health problems, and aesthetic degradation associated with the deterioration of water quality, development of eutrophication, intentional or accidental introduction of invasive species, exacerbated flooding, reduction in the ecosystem productivity, biodiversity loss, and other such ecological changes have profusely hindered to undertake unsustainable water management. The environmental planners or managers are required to pursue the concept of ecologically sustainable water management putting more emphasis on biodiversity conservation with the mandate to justify inherently untenable objective of satisfying society's need for water and its resources.

Water environmental scientists, technocrats, managers' planners, and users all intend to remain associated within the limits posed by ecosystem flow requirements even as undergoing further refinement in order to efficiently use available water supplies, by planning and adopting long-term water resource management strategies. Newly conceived innovative and holistic approaces toward achieving the solution of long-standing conflicts between human needs and availability of water resources are required to tapping and effectively utilizing human creativity for achieving most acceptable resolution.

Proper designing and implementation of water management program with the emphasis to store and also divert water for the multifarious uses of human beings without causing that much of ecodegradation of the river ecosystems are in need to balance in between the amount of water to be withdrawn from a river and maintenance of the river's natural flow patterns without making any alteration. These limits defined by the ecosystem's requirements for water tend to ensure the ecological integrity of the affected ecosystems, without causing the loss of native species and ecosystem goods and services for society. Sustainable water management, being the top priority areas of different actors within human society, including scientists, politicians, water managers, the common peoples, non-governmental organizations (**NGOs**), and industrialists, emphasizes the quantification of the of the inclining trend of water utilization and the deteriorating environmental quality of water and aquatic life which include the problems created by expected sea level rises reflected through climate change projections (Jenkins et al. 2009), overextraction of water from underground aquifers, and increasing demands from growing populations (Vörösmarty et al. 2000).

Therefore, while much effort is being put into improving water management and water ecology internally within these sectors, it appears difficult to create a combined integrated impetus for sustainable water use. However, what is needed is a deeper understanding of exactly why this integration often proves so difficult to achieve, as well as examples of how different groups might be helped to work closer together. Integration in water management involves a wide variety of competing interests, rationalities, and forms of explanation.

The rationality of economics does not necessarily combine comfortably with that of ecology, nor does the understanding of the world presented by anthropologists fit easily into the mathematical constructions of the modelers. Yet, all of these disciplines are parts of "**science**," and all of them have something to contribute to improving water management. A well-known dilemma in water management is the incorporation of (or lack of) scientific information within the policy and management processes. This science–policy interface seems to be the source of much frustration and misunderstanding (Roux et al. 2006). Scientists, whether from the natural or social sciences, complain that policy makers and managers do not take into account the knowledge generated within their disciplines.

Conversely, from the other side, the complaint is that scientists do not provide the kind of knowledge necessary to solve day-to-day problems. A significant factor here seems to be connected with the ways in which problems are formulated, as scientists tend to focus on problems that can be solved, or at least analyzed, through the methods and methodologies that they are trained to use. Policy makers and managers, on the other hand, usually need practical answers to immediate problems.

Policy makers, in their role as politicians or elected officials, also need to take into account the perceptions of their electorate, the people who hopefully will vote for them again the next time around. The differences between these two ways of formulating and understanding problems is significant and sometimes leads to claims that one side lacks a genuine interest in understanding the other's perspectives.

1.23 Sustainable Management of River Ecosystem

Sustainable management of river ecosystem requires an integrated approach of involving different disciplines of science (physical, chemical, geological, biological, and mathematical) and also other branches of social science (sociology, economics, history, etc.) to pay more emphasis to restoration measures to reverse ongoing environmental degradation.

This is thought to be achieved adhering to the pragmatic scientific principles of ecology for understanding the different pathways of river ecosystem. Formulation of policies through adequate research and their implementation by governmental agencies seems pivotal to address the issues. Simultaneously, awareness at community levels and people's participation may also be essential to ensure sustained management programs for the effective maintenance and rejuvenation of surface and subsurface freshwater flows.

Ecologically healthy freshwater ecosystems render a wealth of goods and services for society. Human demands on the world's available freshwater resources have been increased manyfold during the last couple of centuries in tune with the increase of global population. Most of the earlier endeavors for the management of riverine flows with an eye to cater to the need of the human beings have been mostly relied on the water itself keeping aside the requirements for life support of different water-dependent living organisms which have resulted evil ecological consequences. Therefore, the demand of the present mode of water management should focus on better management of freshwater flows in order to sustain these benefits toward freshwater biodiversity.

In such context, a viable and sustainable water management program giving due importance to human needs are required to be devised by storing and diverting water with an aim to restore and maintain the ecological integrity of affected river ecosystems. Different steps of eco-management of river ecosystem should include the followings:

1. Developing baseline qualitative and quantitative data and information in respect of river flow which are required to chalk out necessary plans and actions to sustain native species and natural ecosystem functions.
2. Assessment, enlisting, and recording of different human uses of water, both for the present and future, through the preparation of data base in order to develop of a computerized hydrologic simulation model so that proper recommendation for abating and tackling of human-induced alterations to river flow regimes be made.
3. Evaluating the existing and previous incompatibilities between human and ecosystem needs with special reference to their spatial and temporal changing needs as an river management strategy.
4. Searching for solutions to resolve incompatibilities through collaborative efforts.
5. Undertaking water management strategies to overcome the ecological problems of rivers by integrating human and ecosystem needs.
6. Facilitating ecologically sustainable water management practices by planning and implementing an adaptive management program.

7. Undertaking preservation and protection of biodiversity conservation strategies by adopting pragmatic principles pertaining to the riverine ecology based on the baseline information on tropical Asian rivers. In several parts of the world, growing human populations have resulted rapid depletion of available freshwater supplies.

During the twentieth century, the global human populations have increased fourfold to reach more than six billion (**6 × 109**). The abstraction and withdrawal of water from both natural lentic and lotic freshwater ecosystems have been increased eightfold during the same period (Gleick 1998). In view of ongoing and ever-increasing problems pertaining to the demand and supply of freshwater, environmental scientists, and managers, social planners, and government leaders have been in the process of developing suitable strategies for the sustainable water resource management (IUCN 2000). This quest for achieving sustainability in the freshwater resource management attaches more importance on abating as well as imposing restrictions on the mode of negative human intervention in utilizing water so that enough water of acceptable quality be made available for the use of future generations. Giving more emphasis to meet the freshwater need of human being since the very early period of human civilization till date ignoring the necessary demands and essential the needs of the water by the freshwater species and ecosystems have not only been overlooked but largely neglected which in turn have resulted to tragic ecological consequences (IUCN 2000, Pringle et al. 2000, Stein et al. 2000, Baron et al. 2002).

The alteration of river flow regimes associated with construction of dams causing arrestation coupled with retardation of flowing water of rivers has been assigned as one of the three prime causes for the deterioration of water quality, along with pollution from both point and non-point sources and introduction of invasive species. All of which independently or in conjunction with one another have resulted in the elimination of aquatic animals (Richter et al. 1997a, Pringle et al. 2000). Values, services, and products derived from freshwater ecosystem by human society residing within close vicinity of riverine flows have also been severely compromised and affected (Postel and Carpenter 1997, IUCN 2000).

In order to maintain a balance in between withdrawal of water and meeting of human needs, a water budget has to be formulated to meet both the ends without hampering the natural functioning and productivity of fresh riverine ecosystem. Otherwise, the goods, products, and services rendered by them are severely hampered. The ecologists, being endowed with the responsibilities to assess the structure and function of lotic ecosystem and the politicians knowing very well of their limitations in solving the problems pertaining to the loss of threatened species and also on the deteriorating water qualities of river ecosystem, should encourage and also facilitate for undertaking eco-monitoring, after causing changes in the societal perceptions and values toward the ecological protection and conservation of the nature.

Many examples have emerged from different corners of the globe during the past few decades demonstrating ways and means for meeting human needs of water alongside maintaining the required volume and timing of water flows with an objective of protecting the affected freshwater ecosystems. In such context, the compatible integration of the needs of human being and natural ecosystem should be taken care of. In such context, an integrated, holistic, and comprehensive approach in unraveling the mysteries of interrelationships among different structural components (living and nonliving), meteorological parameters, different eco-geo-biological processes, resilience manifestation in response to ongoing perturbations, and ecological consequences of interconnectivity of rivers with other adjoining ecosystems such as terrestrial, forests, floodplains, and wetlands, both ecological and society-driven biodiversity conservation, becomes very much imperative in tune with the demands of the time.

Increased dependence of human society on rivers for their all-round needs and benefits and the resultant developmental pressures have necessitated systematic, strategic, and integrated conservation planning and management of the rivers and their resource bases mostly adhering to the scientific ecological principle-based knowledge, in consonance with socioeconomic and ecological goals toward the conservation of river ecosystem. Such ecologically holistic and sustainable water management strategies and efforts are expected not only to meet the needs of the moments but also to keep the precious resources such as water and its dependent living and nonliving resources with all their goods and services for making them available for the future generation.

An integrated, holistic, and comprehensive approach have become very much imperative and demands of the time in unraveling the mysteries of interrelationships among different structural components (living and nonliving), meteorological parameters, different eco-geo-biological processes, resilience manifestation in response to ongoing perturbations, and ecological consequences of interconnectivities of rivers with other adjoining ecosystems such as terrestrial, forests, floodplains, and wetlands, both ecological and society driven biodiversity conservation. Increased dependence of human society on rivers for their all-round needs and benefits and the resultant developmental pressures have necessitated strategic and systematic conservation planning and management of the rivers and their resource bases mostly adhering to and strengthened by the scientific ecological principles based knowledge, in consonance with socioeconomic and ecological goals toward conservation of river ecosystem.

However, ongoing onslaughts on rivers in the form of man-made pollution and natural hazards have posed serious threats to the sustainability of riverine resource base during the last few decades at an alarming intensity. Alongside floods, drought remains the major threat today leading to economic recession, depopulation, and political instability. In the present time, rapid population growth and increased per capita demand for water especially within the developing countries has resulted in acute water scarcity. In the past, the river developments have caused dramatic ecological impacts: a loss of habitat diversity, the reduction of species richness, and decline in productivity. However, the modern approach to river development is founded in the concept of environmental sustainability that incorporates the need to conserve biodiversity. Recent research has shown that river margins being the dynamic interfaces between terrestrial and aquatic environments represent the sites of an array of biological processes through the exchange of materials, mass, energy, etc., resulting in higher biological productivity and diversity. The demand for freshwater is met by surface, subsurface, and groundwater sources.

Apart from highlighting the basic ecological concepts, hypotheses, and theories pertaining to freshwater river systems and its biodiversity components unique for tropical biogeographic zones in the face of social and political milieu, the book will highlight the ongoing environmental perturbations and potential of biodiversity and their synergistic effects in ensuring resilience of riverine ecosystem functioning based on original research during last two decades in the riverine networks of South West Bengal, India, and required methodological approaches for the eco-assessment and eco-management of the river ecosystem.

References

Amoros, C., A.L. Roux, J.L. Reygrobellet, J.P. Bravard, and G. Pautou. 1987. A method for applied ecological studies of fluvial hydrosystems. *Regulated Rivers: Research and Management* 1: 17–36.

Andersson, E., C. Nilsson, and M.E. Johansson. 2000. Effects of river fragmentation on plant dispersal and riparian flora. *Regulated Rivers: Research and Management* 16 (1): 83–89.

Angermeier, P.L., and J.R. Karr. 1994. Biological integrity versus biological diversity as policy directives. Protecting biotic resources. *Bioscience* 44: 690–697.

Annandale, N. 1922. The macroscopic fauna of Lake Biwa. *Annotationes Zoologicae Japonenses* 10: 127–153.

Armitage, P.D. 1995. Faunal community change in response to flow manipulation. In *The ecological basis for river management*, ed. D.M. Harper and A.J.D. Ferguson, 59–78. Chichester: Wiley.

Barbour, M.T., J. Gerritsen, G.E. Griffith, R. Frydenborg, E. Mccarron, J.S. White, and M.L. Bastian. 1996. A framework for biological criteria for Florida streams using benthic macroinvertebrates. *Journal of the North American Benthological Society* 15: 185–211.

Barbour, M.T., J. Gerritsen, B.D. Snyder, and J.B. Stribling. 1999. *Rapid bioassessment protocols for use in streams and wadeable rivers: Periphyton, benthic macroinvertebrates and fish*, Rep. EPA/841-B-99-002. 2nd ed. Washington, DC: US EPA, Off. Water.

Baron, J.S., N.L. Poff, P.L. Angermeier, C.N. Dahm, P.H. Gleick, N.G. Hairston, R.B. Jackson, C. A. Johnston, B.D. Richter, and A.D. Steinman. 2002. Meeting ecological and societal needs for freshwater. *Ecological Applications* 12: 1247–1260.

Beven, K.J and Carling, P.A. 1992 Velocities, roughness and dispersion in a lowland River Seven In: Lowland floodplain rivers: Geomorphological perspectives (Eds Carling, P.A and Prtts, G. E.) Wiley, Chichester, 71–93.

Cairns, J., Jr. 1991. Is restoration to predisturbance condition a viable option? *Environmental Professional* 11: 152–159.

Callicott, J.B. 1994. *Earth's insights: A survey of ecological ethics from the Mediterranean Basin to the Australian Outback*. Berkeley: University of California Press.

Callicott, J.B., L.B. Crowder, and K. Mumford. 1999. Current normative concepts in conservation. *Conservation Biology* 13 (1): 22–25.

Carothers, S.W., R.R. Johnson, and S.W. Aitchison. 1974. Population structure and social organization of Southwestern riparian birds. *American Zoologist* 14: 97–108.

Chakraborty, S.K. 2017. Ecological services on intertidal benthic fauna and the sustenance of coastal wetlands along the Midnapore (East) coast, West Bengal, India (Published in the book,

Coastal Wetlands: Alteration and Remediation, Springer International Publishing AG part of Springer Nature), 777–886.
Connell, J.H. 1978. Diversity in tropical rain forests and coral reefs. *Science* 199 (4335): 1302–1310.
Costanza, R., and B.C. Patten. 1995. Defining and predicting sustainability. *Ecological Economics* 15: 193–196.
Costanza, R., F. Sklar, and M. White. 1990. Modelling coastal landscape dynamics. *BioScience* 40: 91–107.
Costanza, Robert et al. 1997. The value of the world's ecosystem services and natural capital. *Nature* 387: 253–260, May 15.
Cummins, K.W., G.W. Minshall, J.R. Sedell, C.E. Cushing, and R.C. Peterson. 1984. Stream ecosystem theory. *Internationale Vereiningung fuer Theoretische und Angewandte Limnologie Verhandlungen* 22: 1818–1827.
De'camps, H., and E. Tabacchi. 1994. Species richness in vegetation along river margins. In *Aquatic ecology: Scale, pattern and process*, ed. P.S. Giller, A.G. Hildrew, and D.G. Rafaelli, 1–20. London: Blackwell.
Dobson, A.P., and J. Foufopoulos. 2001. Emerging infectious pathogens in wildlife. *Philosophical Transactions of the Royal Society of London B* 356: 1001–1012.
Dobson, A.P., A.D. Bradshaw, and A.J.M. Baker. 1997. Hopes for the future: Restoration ecology and conservation biology. *Science* 277: 515–522.
Dorren, L.K., F. Berger, C. Le Hir, E. Mermin, and P. Tardif. 2005. Mechanisms, effects and management implications of rockfall in forests. *Forest Ecology and Management* 215 (1–3): 183–195.
Dudgeon, D. 2000a. Riverine wetlands and biodiversity conservation in tropical Asia. In *Biodiversity in wetlands: Assessment, function and conservation*, ed. B. Gopal, W.J. Junk, and J.A. Davis, 1–26. The Hague: Backhuys.
Dynesius, M., and C. Nilsson. 1994a. Fragmentation and flow regulation of river systems in the Northern Third of the World. *Science* 266: 753–762.
———. 1994b. Fragmentation and flow regulation of river systems in the Northern Third of the World. *Science* 266: 753–762.
———. 1997. Hopes for the future: Restoration ecology and conservation biology. *Science* 277: 515–522.
———. 2000. The ecology of tropical Asian rivers and streams in relation to biodiversity conservation. *Annual Review of Ecology and Systematics* 31: 239–263.
———. 2001. Emerging infectious pathogens in wildlife. *Philosophical Transactions of the Royal Society of London B* 356: 1001–1012.
Environment and Development. 1987. Report of the world Commission on environment and development. In *Our common future*, 1–223. Geneva: Centre for Our Common Future.
Friberg, N., B. Kronvang, H.O. Hansen, and L.M. Svendsen. 1998. Long-term, habitat-specific response of a macroinvertebrate community to river restoration. *Aquatic Conservation: Marine and Freshwater Ecosystems* 8: 87–99.
Gibbons, D.W., and D. Pain. 1992. The influence of river flow rate on the breeding behavior of Calopteryx damselflies. *Journal of Animal Ecology* 61: 283–289.
Gleick, P.H. 2000. *The world's water: 2000–2001*. Washington DC: Island Press.
Gopal, B. 1997. Biodiversity in inland aquatic ecosystems in India: An overview. *International Journal of Ecology and Environmental Sciences* 23: 305–313.
Gopal, B, and Zutshi, D.P. 1998. Fifty years of hydrobiological research in India. *Hydrobiologia* 384: 267–290.
Hamilton, F. 1822. *An account of the fishes found in the river Ganges and its branches*. Edinburgh/London: Archibald Constable and Co./Hurst, Robinson & Co.
Hemphill, N., and S. Cooper. 1983. The effect of physical disturbance on the relative abundance of two filter -feeding insects in a small stream. *Oecologia* 58 (3): 378–382.

Hildrew, A.G., and C.R. Townsend. 1987. Oganization in freshwater benthic communities. In *Organization of Communities Past and Present, 27th Symposium of the British Ecological Society, Aberystwyth, 1986*, ed. J.H.R. Gee and P.S. Giller, 1st ed., 347–372. Oxford: Blackwell Science.

Hildrew, A.G., C.R. Townsend, and J. Francis. 1984. Community structure in some southern English streams: The influence of species interactions. *Freshwater Biology* 14: 297–310.

Hynes, H.B.N. 1960. *The biology of polluted waters*. Liverpool: Liverpool University Press.

———. 1970a. *The ecology of running waters*. Toronto: University of Toronto Press.

———. 1970b. The ecology of stream insects. *Annual Review of Entomology* 15: 25–42.

IUCN (International Union for the Conservation of Nature). 2000. *Vision for water and nature: A world strategy for conservation and sustainable management of water resources in the 21st century*. Gland; Cambridge, UK: International Union for the Conservation of Nature.

Junk, W.J., P.B. Bayley, and R.E. Sparks. 1989. The flood pulse concept in river-floodplain systems. In *Proceedings of the International Large River Symposium, Can. Spec. Publ. Fish. Aquat. Sci., ed. DP Dodge*, vol. 106, 110–127.

Karr, J.R. 1981. Assessment of biotic integrity using fish communities. *Fisheries* 6: 21–27.

Karr, J.R., and E.W. Chu. 1999. *Restoring life in running waters: Better biological monitoring*. Washington, DC: Island Press.

Keenleyside, K.A., N. Dudley, S. Cairns, C.M. Hall, and S. Stolton. 2012. *Ecological restoration for protected areas: Principles, guidelines and best practices*, 1–120. Gland: IUCN.

LaBonte, James R. 2001. Nebria brevicollis (Fabricius 1792) in North America, benign or malign ? (coleoptera, carabidae, Nebriini). *ZooKeys* 147: 527–543.

Ladle, M., and R.J. Ladle. 1992. Life history patterns of river invertebrates. *Hydrobiologia* 248 (1): 31–37.

Lamberts, D., and J. Koponen. 2008. Flood-pulse alterations and productivity of the Tonle Sap ecosystem: A model for impact assessment. *Ambio* 37: 178–184.

Leuven, Rob S.E.W., Gerad van der Velde, I. Baijens, J. Snijders, Christien van der Zwart, H.J. Rob Lenders, and Abraham bij de Vaate. 2009. The river Rhine: A global highway for dispersal of aquatic invasive species. *Biological Invasions* 11: 1989–2008.

Ligon, F.K., W.E. Dietrich, and W.J. Trush. 1995. Downstream ecological effects of dams. *Bioscience* 45: 183–192.

McAuliffe, J.R. 1984. Competition for space, disturbance, and the structure of a benthic stream community. *Ecology* 65: 894–908.

McCormick, P.V., and R.J. Stevenson. 1989. Effects of snail grazing on benthic algal community structure in different nutrient environments. *Journal of the North American Benthological Society* 82: 162–172.

Mills, E.L., R.M. Dermott, E.F. Roseman, D. Dustin, E. Mellina, D.B. Conn, and A.P. Spidle. 1993. Colonization, ecology, and population structure of the “Quagga” mussel (Bivalvia: Dreissenidae) in the lower Great Lakes. *Canadian Journal of Fishery and Aquatic Sciences* 50: 2305–2314.

Minshall, G.W. 1984. Aquatic insect-substratum relationships. In *The ecology of aquatic insects*, ed. V.H. Resh and D.M. Rosenberg, 358–400. New York: Praeger Publishers.

Minshall, G.W. 1988. Stream ecosystem theory: A global perspective. *Journal of the North American Benthological Society* 7: 263–288.

Minshall, G.W., and J.N. Minshall. 1977. Microdistribution of benthic invertebrates in a Rocky Mountain (U.S.A.) stream. *Hydrobiologia* 55: 231–249.

Minshall, G.W., J.T. Brock, and T.W. LaPoint. 1982. Characterization and dynamics of benthic organic matter and invertebrate functional feeding group relationships in the upper Salmon River, Idaho (USA). *Internationale Revue der Gesamten Hydrobiologie* 67: 793–820.

Minshall, G.W., R.C. Peterson, K.W. Cummins, T.L. Bott, J.R. Sedell, C.E. Cushing, and R.L. Vannote. 1983. Interbiome comparison of stream ecosys- tem dynamics. *Ecological Monographs* 53: 1–25.

Minshall, G.W., K.W. Cummins, R.C. Petersen, C.E. Cushing, D.A. Bruns, J.R. Sedell, and R.L. Vannote. 1985. Developments in stream ecosystem theory. *Canadian Journal of Fisheries and Aquatic Sciences* 42: 1045–1055.

Minckley, W.L. 1963. The ecology of a spring stream, Doe Run, Meade County, Kentucky. *Wildlife Monographs* 11: 1–124.

Minckley, W.L., and J.E. Deacon, eds. 1991. *Battle against extinction: Native fish management in the American West*. Tucson: University of Arizona Press. 535 pp.

Minckley, W.L., and M.E. Douglas. 1991. Discovery and extinction of western fishes: A blink of the eye in geologic time. In *Battle against extinction: Native Fish management in the American West*, ed. W.L. Minckley and J.E. Deacon, 7–17. Tucson: University of Arizona Press.

Moles, A.T., and M. Westoby. 2000. Do small leaves expand faster than large leaves, and do shorter expansion times reduce herbivore damage? *Oikos* 90: 517–524.

Mooney, H.A. 1991. Biological response to climate change: An agenda for research. *Ecological Applications* 1: 112–117.

Naiman, R., and R. Bilby, eds. 1998. *River ecology and management: Lessons from the pacific coastal ecoregion*, 1–73. New York: Springer.

Naiman, R.J., H. Decamps, J. Pastor, and C.A. Johnston. 1988. The potential importance of boundaries to fluvial ecosystems. *Journal of the North American Benthological Society* 7: 289–306.

Norris, R.H., and M.C. Thomas. 1999. What is river health? *Freshwater Biology* 41: 197–209.

Pearsons, T.N., H.W. Li, and G.A. Lamberti. 1992. Influence of habitat complexity on resistance to flooding and resilience of stream fish assemblages. *Transactions of the American Fisheries Society* 121: 427–436.

Poff, N.L. 1997. Landscape filters and species traits: Toward mechanistic understanding and prediction in stream ecology. *Journal of the North American Benthological Society* 16: 391–409.

Poff, N.L., J.D. Allan, M.B. Bain, J.R. Karr, K.L. Prestegaard, B.D. Richter, R.E. Sparks, and J.C. Stromberg. 1997. The natural flow regime: A paradigm for river conservation and restoration. *BioScience* 47: 769–784.

Postel, Sandra, and Stephen Carpenter. 1997. Freshwater ecosystem services. In *Nature's services: Societal dependence on natural ecosystems*, ed. Gretchen C. Daily, 195–214. Washington, DC: Island Press.

Pringle, C.M., M.C. Freeman, and B.J. Freeman. 2000. Regional effects of hydrological alterations on riverine macrobiota in the New World: Tropical-temperate comparisons. *BioScience* 50: 807–823.

Richter, B.D., J.V. Baumgartner, J. Powell, and D.P. Braun. 1996. A method for assessing hydrologic alteration within ecosystems. *Conservation Biology* 10 (4): 1163–1174.

Ricklefs, R.E., and D. Schluter. 1993. Species diversity: Regional and historical influences. In *Species diversity in ecological communities*, ed. R.E. Ricklefs and D. Schluter, 350–363. Chicago: University of Chicago Press.

Roux, Clément, Adrien Alber, Mélanie Bertrand, Lise Vaudor, and Hervé Piégay. 2015. "FluvialCorridor": A new ArcGIS toolbox package for multiscale riverscape exploration. *Geomorphology* 242 (2015): 29–37.

Stein, J.L., J.A. Stein, and H.A. Nix. 2002. Spatial analysis of anthropogenic river disturbance at regional and continental scales: Identifying the wild rivers of Australia. *Landscape and Urban Planning* 60: 1–25.

Tabacchi, E., and A.-M. Planty-Tabacchi. 2000. Riparian plant community composition and the surrounding landscape: Functional functional significance of incomers. In *Riparian ecology and management in multi-land use watersheds*, ed. P.J. Wigington Jr. and R.L. Beschta, 11–16. Corvallis: Proceedings of the AWRA's 2000 Summer Conference.

Tabacchi, E., A. Planty-Tabacchi, M.J. Salinas, and H. Décamps. 1996. Landscape structure and diversity in riparian plant communities: A longitudinal comparative study. *Regulated Rivers: Research and Management* 12: 367–390.

United Nations (UN). 1998. Kyoto protocol to the United Nations framework convention on climate change. Convention on Climate Change, Bonn, Germany. Available from https://unfccc.int/kyoto.protocol/items/2830.php Accessed February 2009.

United Nations Environmental Program. 2007. *Global environmental outlook 4*. New York: UNEP.

Vörösmarty, C.J., P.B. McIntyre, M.O. Gessner, D. Dudgeon, A. Prusevich, P. Green, S. Glidden, S.E. Bunn, C.A. Sullivan, C.R. Liermann, et al. 2010. Global threats to human water security and river biodiversity. *Nature* 467: 555–561.

Walker, J., C.H. Thompson, P. Reddell, and D.J. Rapport. 2001. The importance of landscape age in influencing landscape health. *Ecosystem Health* 7: 7–14.

Walker, J.S., N.B. Grimm, J.M. Briggs, C. Gries, and L. Dugan. 2009. Effects of urbanization on plant species diversity in central Arizona. *Frontiers in Ecology and the Environment* 7: 465–470.

Warren, C.E. 1971. *Biology and water pollution control*, 1–434. Philadelphia: W. B. Saunders.

Ward, J., and J.A. Stanford. 1983a. The intermediate-disturbance hypothesis: An explanation for biotic diversity patterns in lotic ecosystems. In *Dynamics of lotic ecosystems*, ed. F. Fontaine, 347–355. Ann Arbor: Ann Arbor Press.

———. 1983b. The serial discontinuity concept of lotic ecosystems. In *Dynamics of lotic ecosystems*, ed. T.D. Fontaine and S.M. Bartell, 29–42. Ann Arbor: Ann Arbor Science.

———. 1983c. The intermediate disturbance hypothesis: An explanation for biotic diversity patterns in lotic ecosystems. In *Dynamics of lotic ecosystems*, ed. T.D. Fontaine and S.M. Bartell, 347–356. Ann Arbor: Ann Arbor Science Publishers.

Waters, T.F. 1995. *Sediment in streams: Sources, biological effects and control*. Bethesda: American Fisheries Society. 251 pp.

Welcomme, R.L. 1979. *Fisheries ecology of flood plain rivers*, 1–317. London: Longman.

———. 1985. *River fisheries*, F.A.O. fisheries technology paper, 262, 1–330. Rome: FAO.

Welcomme, and M.J. Winterbourn. 1988. Patch dynamics in lotic systems: The stream as a mosaic. *Journal of the North American Benthological Society* 7: 503–524.

Westlake, D.F., and F.H. Dawson. 1982. Thirty years of weed cutting on a chalk stream. In *Proceedings EWRS 6th Symposium on Aquatic Weeds*, 132–140.

Wetzel, R.G. 2001. *Lymnology: Lake and river ecosystems*. London: Academic.

Chapter 2
Biodiversity: Concept, Theories, and Significance in River Ecology

Abstract Biological diversity in nature is being viewed as a product of ongoing evolutionary events on existing biotic communities. Diversity found within and among keystone predator populations can have the potential to influence the future direction of diversity at three levels of eco-biological processes such as biological organization, from the lowest level of biomolecules (genes) to the highest hierarchical form as ecosystems, and through eco-evolutionary feedbacks. At present, species extinction has progressed rapidly, with an accelerating rate, due to human-mediated disturbances ranging from local human activities to global climate change. India as one of the **18** megadiversity countries having **4** out of **34** hot spots of the world not only boasts of accommodating a very rich biodiversity wealth in terms of species diversity but is naturally gifted with an innumerable variability of genes (genetic diversity) within species along with harboring an enormous numbers of endemic species in **3** major biological realms (Indo-Malayan, Eurasian and Afrotropical), **10** biogeographic zones and **26** biotic provinces.

Keywords Biodiversity · Endemism and endemic species · Hot spots · Biological realms · Biogeographic zones · Riverine biotic assemblages · Functional diversity · Habitat heterogeneities · Trophic complexity · Trophic polymorphism · Evolutionary resilience · Adaptive divergence · Ecosystem engineers · Biodiversity–ecosystem functioning (BEF) · Ecological service providers · Aquatic bioinvasion · Endangered and vulnerable species · Eco-complementation · The Convention on Biological Diversity(CBD) · Sustainable biodiversity conservation

Loss of biodiversity, especially in other threatened landscapes of the world and fresh water wetlands including rivers, streams, lakes, floodplains, etc. has become a leading global environmental issue. Alongside paying serious attention to the conservation of species, specifically those that are endangered, conservation of the functional diversity of keystone species within and among populations is also important as the effects of predator functional diversity can sometimes even extend to different functional attributes of ecosystem in respect of energy flows and nutrient

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cycling, from which several beneficial and profitable forms of goods and services of ecosystem for human well-being can be derived.

Considering its ecological and economic significance, assessment, and conservation of biodiversity of different landscapes, biomes and ecosystems across the globe having an aim at ensuring sustainability have been a challenging task for the researchers, environmental planners, policy makers, and administrators during the last several decades. River ecosystem with its associated geomorphological components such as streams, rivulets, floodplains, river basins and catchments, watersheds, and different forms of lentic wetlands offer not only habitat heterogeneities but also an array of biodiversity components (macrophytes, microphytes, microbes, plankton, benthos, periphyton, nektons, etc.) which inhabit different riverine landscapes.

Recording and highlighting the functional roles of different biodiversity components in the riverine tracts are also important in view of ongoing and escalating anthropogenic activities leading to biodiversity loss in and around riverine ecosystem. Global biodiversity loss has become an acute crisis, and the need of the moment is to tackle this problem by undertaking regional and local research ventures, the outcomes of which in turn demand positive global response (IUCN(2000); Chakravarty et al. (2004); Chakraborty, 2017, 2018; Chatterjee (2018); Cummins (1966); Elmqvist et al. (2003); Frost et al. (2005); Glowka et al. (1994); Greenberg et al. (1985); Gunter (1961); Halder Mallick and Chakraborty (2014), Halder Mallick and Chakraborty (2016), HalderMallick et al. (2013); Naiman et al. (1986)).

The Convention on Biological Diversity (**CBD**) and Global Environment Facility (**GEF**) have developed legal and financial frameworks, respectively, for generating the rationale and standards to combat the problems of biodiversity loss. In such context, the present chapter has highlighted different theoretical and applied aspects of riverine biodiversity clarifying different terminologies with definitions and examples, trophic relationships, and distributional patterns putting due emphasis on research findings from the southwestern part of the state of West Bengal, India. The twofold challenges before the human civilization for the conservation of biodiversity are, **first**, to understand the ways and means to ensure sustainable development along with protection of biodiversity based on identification and realization the root causes for the loss of biodiversity and **second** to translate such knowledge into systematic and strategic activities involving all affected actors, starting from the top to local levels.

2.1 What Is Biological Diversity?

The statement made by Wilson (1992) is pertinent to understand about the significance of biodiversity. Elimination of one species may be replaced by another, but ousting of great many species causes initiation of a visible decay of local ecosystem.

The impact of such loss of biodiversity is reflected by the dropping of productivity mostly because of the clogging of nutrient cycles, higher sequestration of biomass as dead vegetation and experience slow metabolism, deficiency of oxygen in the bottom water and sediment, lowering of pH, and massive erosion of soils. A drastic change of species composition results in more activities of less competent pollinators dislodging best-adapted bees, moths, birds, bats, and other ecofriendly biotic components, hindrance in the dispersal of seeds and sprouting of seedlings, and declining of the numbers of herbivores resulting in the death of potential key stone predators.

2.2 Concept and Definition of Biodiversity

The term **biodiversity** has actually enunciated from conservation biology. In **1992**, in the book of Edward O. Wilson used the phrase, *The Diversity of Life*, the main aim of that publication was to draw attention to species loss and especially putting more stress on the human-mediated stresses on the biological world towards massive extinction event since the **1970s**."

The studies on biodiversity are intimately connected with another emerging field of science, the conservation biology which mainly deals with recording, documentation of conservation categories of species, and establishing the reasons behind the decline of biodiversity along with chalking out proper conserving strategies for the depleting population of recorded flora and fauna suggesting prospective pathways for their eco-rehabilitation and thereby eco-restoration of the habitats.

The conservation biologists take into consideration different dimensions of wild nature starting from the assessing of gene pools: consistent genetic differences with magnitude among populations, variability within population, and reproductive isolation as a cause of divergence of gene pools. More emphasis was given on the underlying scientific principles leading to evolutionary resilience of vulnerable species against changing ecological setups and the genetic load imposed on these populations by forced inbreeding because of the impacts of in the isolated habitats.

The upshot of this line of thought focuses causally consequential but hidden dimension of biodiversity along with the genetic variability of a population or species. Conservation biologists have typically been interested in population-level properties of a species and their consequences, the size of population, the mode of fragmentation and metapopulation dynamics, age, and sex structure.

In the riverine ecosystem, individualism implies that ecological communities are predominantly modular, and hence the removal of one species is unlikely to have important consequences for most other populations. due to changes of on In addition, individualism makes the biotic community more sensitive against perturbations abiotic conditions, because of the diversion of water for irrigation, or receiving nutrient-filled runoff and industrial discharges within the riverine flows.

Although biodiversity and its protection is considered as the fundamental to the goals of conservation biology, the policies and strategies so far that have been tested have failed to match of the consensus on the significance of biodiversity keeping in mind the technical problem of biodiversity assessment.

Excessive proliferation of the biodiversity measurement strategies, during the recent past, did also not agree with the paucity of available theories aimed at evaluating and comparing efforts in spatiotemporal scales in order to harvest fruitful and successful outcomes. **The United Nations Convention on Biological Diversity** defines biodiversity in **Article 2** as: "'**Biological diversity**' refers to the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; and this includes diversity within species, between species and of ecosystems".

Such conceptual approach puts more stress on relating "**biodiversity**" with "**all living organisms**." However, for the conservation biologists, this definition is of little use as the field of conservation biology is more concerned in complex environmental policy issues with the central focus on ecosystem management which mostly emphasizes on broad-scale and inclusive approach towards a healthy human–land relationship.

It involves the development of proper methodologies for biodiversity measurement and its conservation planning. Planning always involves choices and sacrificing one system to save another and contributes to more practical and effective ways in the policy process.

2.3 Biodiversity at Three Levels

The Convention on Biological Diversity (**CBD, 1992**) has viewed and explained biodiversity as a composite biological organization from genes to ecosystems which encompasses three tiers of levels such as diversity within species, between species, and of ecosystems.

Conservation biology takes into account the maintenance of intraspecific diversity with ecological significance because a population with a variety of phenotypes must possess the adaptive ability against unpredictable environmental changes such as habitat alteration, climate change, and preemergence of pathogens, enabling the prevention of extinction. Recent scientific achievements in the field of molecular biology in general and community genetics in particular have provided a new insight with regard to the ecological and evolutionary consequences of intraspecific diversity.

2.4 Biodiversity and Ecosystem Functioning

Influencing roles of biodiversity over ecosystem functioning and its concomitant effects on human well-being. Although the contemporary concept and significance of biodiversity towards insuring sustainable ecosystem management emerged only in **1992** (the year of the establishment of the **United Nations Convention on Biological Diversity**, **Convention of the Earth Summit in Rio**, and **the United**

Nations Framework Convention on Climate Change), the focuses on different realms of biodiversity have been evolved rapidly through three different stages:

Firstly, it survived the contentious confirmatory years of the late **1990s**, moved through an exploratory phase at the beginning of this century, and is now in the throes of building a new, joint, natural–social model for humanity.

Secondly, major thrust has been made for addressing the ways and means for the estimation of values generated from ecosystem services, and also for undertaking measures for the proper assessment of the roles played by the biodiversity sustaining the ongoing changes of ecological conditions that underpin the production of services. Barbier et al. (1992) have made an economic assessment of the services rendered by an ecosystem keeping in mind several requirements and demands of human beings alongside highlighting the prospective ways and means to meeting those needs. They have stressed upon the acceptable and useful approaches for the valuation of the biological resources that support not only provisioning services (the production of foods, fuels, and fibers) but also cultural services (the nonconsumptive enjoyment of landscapes for recreational, educational, scientific, spiritual, or cultural reasons) and regulating services. In the last case, the economic theory of portfolio choice provides a natural way to investigate the implications of biodiversity for risk management.

Thirdly, emphasis was attached for the inclusion of ecosystem components into economic decision models. In the gamut of conservation biology, it could be argued that maintenance of intraspecific phenotypic variation has the advantage of increasing population viability because larger population with the requisite adaptability can respond to changing environments more effectively. However, such a traditional view has been replaced by recent ecological findings that the intraspecific diversity of a keystone species tends to impose impact substantially on biological communities and their ecosystem functioning.

2.4.1 Biodiversity Analyses: Aquatic vs Terrestrial

The biodiversity by virtue of its multifarious roles towards human benefits not only commands attention but prompted extensive studies considering different levels of the biological hierarchy starting from the lowest form as genes to the highest level as ecosystems (Noss 1990). Among these levels, species richness (usually defined as the number of species of a specific taxonomic group in a specific area), being an essential component of biotic community, serves as key variable in directing different ecological studies for the ecoassessment of biodiversity wealth in an eco–region (Cardinale et al. 2002)., Human societies also give more importance on species richness for biophilic reasons, alongside the possibility of harvesting the goods and services provided by biodiversity (Wilson 1986).

In general, researches on species richness have been oriented in three different directions:

1. As a response variable
2. As an explanatory variable
3. As a variable to be estimated

Besides, three more categories of functional contribution of species richness have been highlighted by several ecologists based on their research studies undertaken in different parts of the world:

First, species richness acts as the main response variable focusing upon latitudinal and areal gradients in the studies of species richness (MacArthur 1967; Rohde 1992) which also prompted to undertake similar studies on oscillations of species richness over time (Sala et al. 2000) and variability of species richness in response to other environmental gradients such as altitude, water depth, nutrients, and primary productivity (Rahbek 1995; Dodson et al. 2000).

Second, species richness serves as a key predictor (explanatory) variable, depicting ecosystem functioning (Loreau et al. 2001), ecosystem services, (Cardinale et al. 2002), and roles of other biological variables which include the introduction of bioinvasive (alien) species (Boggero et al. 2014a). The application of biodiversity as an explanatory variable has now been considered as the **biodiversity–ecosystem function (BEF)** paradigm (Naeem 2002a, b). Despite the recognition of the contribution of biodiversity in ecological studies and its roles for humanity, have triggered the pressing need of the quantitative assessment of biodiversity more accurately, in order to justify its linkages with several acceptable and established ecological concepts, hypotheses and theories, .

Third, comparisons among different aquatic and terrestrial ecosystems have prompted to emerge a new area in ecological sciences, scientifically named as cross-systems ecology (Rotjan and Idjadi 2013) and that has been serving with more precisions and focuses to interpret the ecological findings (Webb 2012). Several research studies have been attempted to arrive at definite conclusion after comparing the aquatic habitats with the terrestrial ones, for example, in respect of food web structure (Shurin et al. 2006), the responses of food web dynamics to resource pulses (Nowlin et al 2008), size structure (Yvon-Durocher et al. 2011), competition strengths (Gurevitch et al. 1992), the roles detrital contribution on primary producers and consumers (Hagen et al. 2012), the strength of trophic cascades (Shurin et al. 2002), decomposition (Treplin and Zimmer 2012), grazing (Burkepile, 2013), dispersal processes (Kinlan and Gaines, 2003) and species richness (Hillebrand 2004).

Thus, given the disproportionate contribution of aquatic systems to global biodiversity particularly in different forms of freshwater ecosystems (Dudgeon et al. 2006; Balian et al. 2008), research efforts on biodiversity analyses both at the local and global scales in different domains of aquatic ecology should be enhanced (Balian et al. 2008) paying more attention on simultaneous ecological studies in different aquatic habitats because ecological concepts get more acceptability and considerable scientific gains after being applied to marine, freshwater, and terrestrial ecosystems (Estes et al. 2011). A more taxonomic bias on biodiversity studies does not generate useful research information because most of the investigations were conducted on plants in the terrestrial habitat and fish and macro-invertebrates in the aquatic habitat (Hoeinghaus et al. 2009) and the lack of studies employing macrophytes with their functional contribution in both freshwater and marine ecosystems (Duarte 2002; Engelhardt and Ritchie 2002).

The studies employing the **biodiversity–ecosystem function** paradigm have been relatively underrepresented in both types of ecosystems, the terrestrial and aquatic (Sequeira et al. 2015). The large use of species richness is being considered as a response variable of biodiversity to ecosystem functions and services (Naeem 2002; Engelhardt and Ritchie 2002; Cardinale et al. 2002). Aquatic and terrestrial ecologists have been pursuing similar questions, without having that much of differences in between them.

However, studies on aquatic systems, compared to terrestrial systems, appear to be less focused on general themes (latitudinal gradients, area, and isolation effects; Hortal et al. 2014). Two undermentioned major aspects of aquatic ecology have been emphasized in the gamut of general ecology:

1. The advance of the trophic cascade concept (Carpenter and Kitchell 1988)
2. The concept pertaining to the metacommunity ecology (Logue et al. 2011)

A challenge for aquatic ecologists is to continue being constructive for a broader ecological perspective at the time of undertaking any ecological research venture with proper plans, design, methods, and performance on aquatic systems.

New but innovative methods for accounting of confounding factors, such as spatial and phylogenetic effects, are to be used to derive more reliable results (Boggero et al. 2014). This could be achieved dealing with two of the following aspects:

First, phylogenetic information may not be readily available for most animal and plant groups, although there have been great advances for some groups (Stevens 2001 for angiosperms and Meredith et al. 2011 for mammals).

Second, despite the many scientific and technological developments, that are now available, many researchers dealing with the subject are not familiar with the latest developed software packages for phylogenetic analysis, interpretation, and implementation.

Two challenges before aquatic and terrestrial ecologists are to develop archives of phylogenetic information on vast range of organisms inhabiting different parts of the world and also to initiate process of incorporating tools and methods from evolutionary studies into the studies on ecology (Jenkins 2014) In summary, it can be suggested that (**1**) no clear differences exist in the way aquatic and terrestrial ecologists work and in their impact on the scientific community with regard to biodiversity studies but that (**2**) an increase in biodiversity analyses is still needed (**Fig. 2.1**).

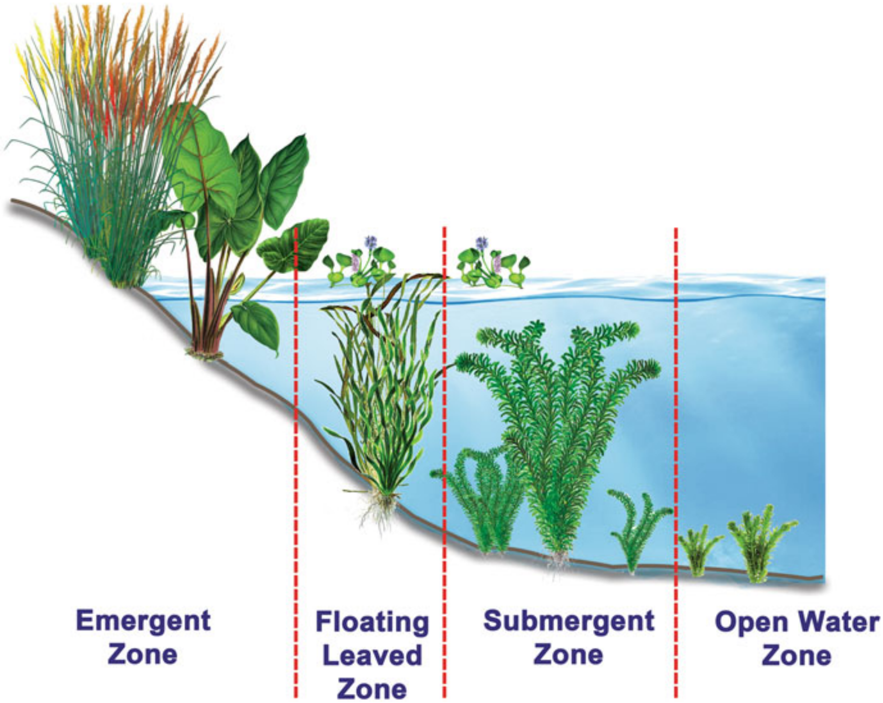

Fig. 2.1 Different zones of freshwater ecosystems demarcated by the distribution and succession of aquatic green plants

2.4.2 *Biodiversity and Trophic Complexity*

A multitude of researches dealing with the different dimensions of biodiversity and its relationship with ecosystem functioning emphasizes more on to the definition, quantification, and applicability of the functional diversity to interpret the roles of biodiversity and its changes in time scales in influencing the ecosystem functioning which have also expanded to include important elements of ecological systems previously understudied such as trophic complexity.

Similarly, research pertaining to the relationship between biodiversity and stability has also gone beyond the initial attempt to simply confirm if there was or was not a relationship between the two to recognizing multiple relationships (mostly positive, some neutral, and a few negative), and multiple mechanisms theory has also gone well beyond resource-based or Lotka–Volterra-type models to explore multitrophic systems, metacommunities, and other theoretical advances.

Giving due importance on environmental concerns and several recommendations put forward by the environmentalists during the **1990s**, several research areas have been originated as a synthesis of the relatively disparate fields of community and ecosystem ecology. In view of the worldwide declines of biodiversity, the major thrust of such researches mostly highlights the following:

1. Species richness was the primary way of operationally defining and manipulating biodiversity.
2. Most of the studies are restricted only on and within a particular trophic level especially on autotrophic plants.
3. Research efforts mainly centered on biogeochemical processes and primary productivity as ecosystem functions.
4. The prevailing mechanisms were often viewed as opposing hypotheses limited to niche complementation, i.e., niche differences lead to greater exploitation of available resources and thereby greater levels of ecosystem functioning and selection effects, i.e., higher diversity communities invariably contain a number of dominant species with disproportionate influences over ecosystem function.
5. Local extinction through the continuous and random processes of biodiversity loss led to produce as many randomly constructed species combinations as possible so that the impact of biodiversity loss on ecosystem functioning could be adjudged.
6. The research was largely experimental, complex, and confirmatory in nature to find out the impact of changes in biodiversity on ecosystem functioning.
7. Researches on biodiversity and their roles in ecosystem functioning have evolved dramatically during the last few decades inviting a lot of contradictions and debate on research findings.

Virtually everything that characterized the first generation of this kind of research functioning research has been changed because of the following:

1. Instead of putting more emphasis on species or functional group richness, the new focus is on trait-based, functional biodiversity, as well as on community composition.
2. Biodiversity along with studies in ecosystem functioning has been increasing on multitrophic and span both in terrestrial and marine ecosystems in comparison to other ecosystems.
3. Trait-based mechanisms have become a major thrust for contemporary research and research on the ecology of flora and fauna, while niche complementarity and selection effects are considered complimentary mechanisms.
4. Trait-based extinction probabilities have been given more emphasis rather than assuming random local extinctions on different biodiversity components in their respective ecological conditions.
5. Much emphasis has been laid on the roles of different biodiversity components along with their roles within an ecosystem in fields of restoration ecology, agriculture, invasions, disease, pollination, climate change, and ecosystem service-related environmental issues than basic first generation of biodiversity research.

Considering all of the above inferences, consensus has been achieved (Loreau et al. 2001, 2002; Hooper et al. 2005) and the debate that once clouded the interpretation of the research findings on biodiversity, their functional roles, and mode of ecosystem functioning has largely abated. There are also entirely new features of the second generation of biodiversity and ecosystem functioning research as well which consider the following:

1. Based on several studies on different dimensions on biodiversity, emphasis has been laid on meta-analyses of newly generated and accumulated research information pertaining to biodiversity which obviate the sometimes subjective interpretation of trends in the experimental analysis of the ecosystem functioning involving biodiversity.
2. An entirely new, innovative, and fruitful method has been developed for undertaking large-scale and long-term research based on the trait-based simulation modeling of relationships of biodiversity and ecosystem functioning has emerged in the arena of ecological studies.
3. Scope of applicability of metacommunity theory for the quantitative assessment of the biodiversity in the fragmented habitats affords additional understanding of ecosystem complexity and stability.
4. Conceptualizing ecosystem processes and functioning as contributory factors towards generation of ecosystem services that tend to provide direct or indirect benefits to the people. This direction of perception and research has made it natural to analyze the trade-offs (in terms of ecosystem services) of alternative ecological configurations and also to compel economists to pay serious attention to the ecological stocks and flows that drive the production of many ecosystem services.

2.5 Biodiversity of Rivers: Tropics vs Temperate

A large number of species inhabit tropical rivers. The number of fish species in tropical rivers is much higher than in temperate rivers, for example, the Mississippi River basin, which acts as the most favored habitats and homes for a galaxy of temperate fish faunas (about **300** fish species). By contrast, the tropical Congo River basin supports the lives of about **669 s**pecies of fish, of which over **558** are found nowhere else.

The most impressive array of freshwater fish diversity is reported from the Amazon River basin, from where more than **2, 000** species have been documented which represent approximately **10%** of all the known fish species on the planet. Most of the large-sized invertebrates of streams and rivers live as the benthic, and most are benthic fauna of which some live in deep within the sediments of rivers in both the hyporheic and phreatic zones. A large number of microscopic organisms spend their lives as pelagic planktonic forms. The organisms of river systems change from headwaters to mouth (Dudgeon, 1992a, b, 1993, 1995a, b, 2000a, b, 2003, Dudgeon et al. 2006; Ismail, 1994). These patterns of biological variation along the courses of rivers have given rise to a variety of theories that predict downstream change in rivers and their inhabitants (**Figs. 2.1, 2.2, 2.3, 2.4, 2.5, 2.6, 2.7, and 2.8**).

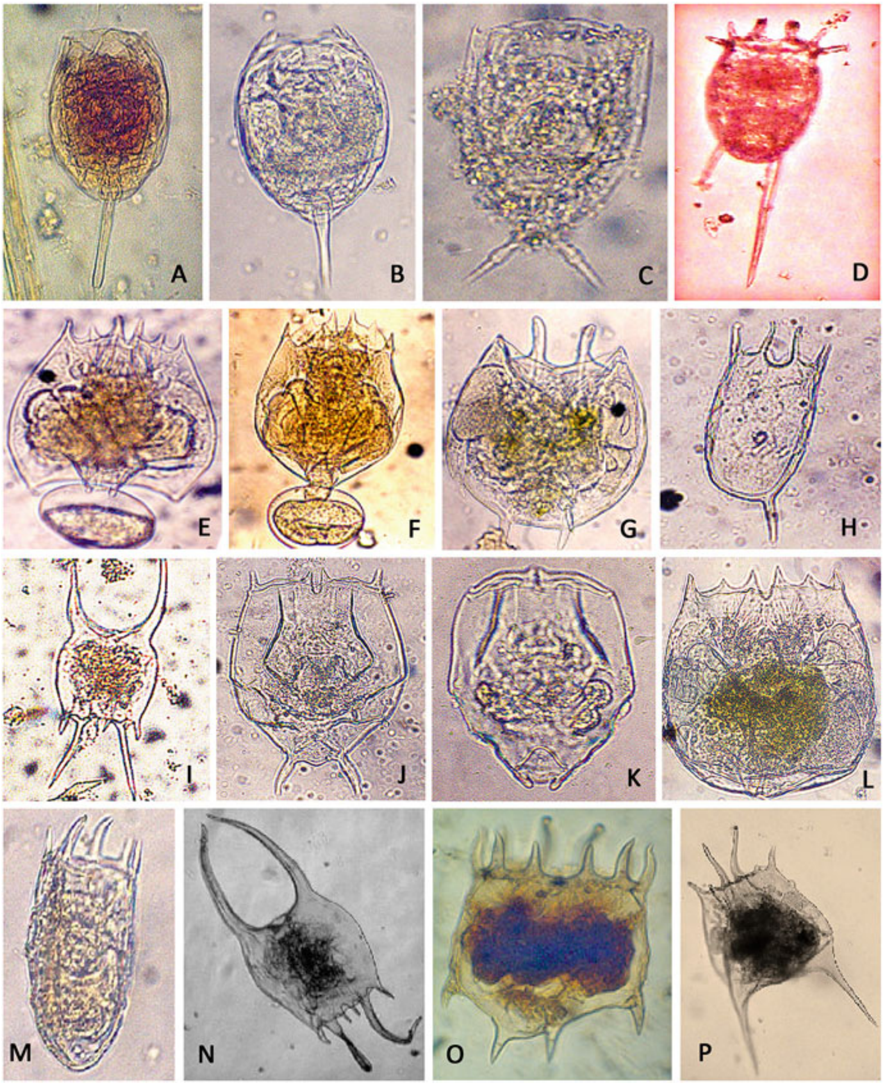

Fig. 2.2 Representative forms of diversity of rotiferan zooplankton **A**. *Lecane lunaris lunaris*, **B**. *Lecane stenroosi*, **C**. *Lecane crepida*, **D**. *Keratella tropica*, **E**. *Brachionus quadridentatus rhenanus*, **F**. *Brachionus rubens*, **G**. *Platyias quadricornis*, **H**. *Keratella cochlearis*, **I**. *Brachionus falcatus*, **J**. *Brachionus caudatus personages*, **K**. *Brachionus angularis*, **L**. *Brachionus bidentata jirovci*, **M**. *Keratella cochlearis*, **N**. *Brachionus falcatus*, **O**. *Brachionus patulus*, **P**. *Brachionus quadridentatus quadridentatus*

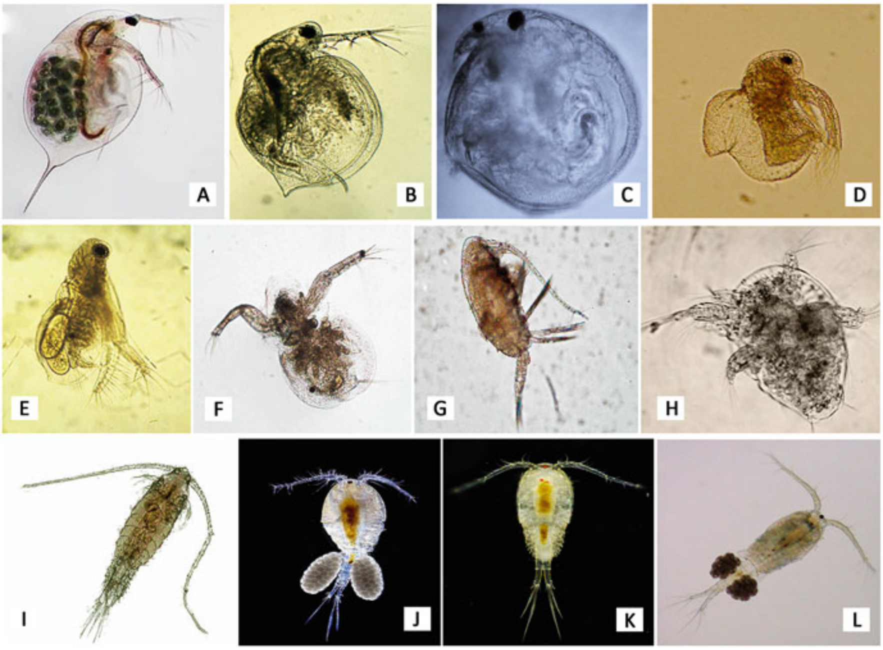

Fig. 2.3 Representative forms of diversity of zooplankton (Copepoda and Cladocera). **A**) *Daphnia carinata*, **B**) *Ceriodaphnia cornuta*, **C**) *Pleuroxus similis*, **D**) *Ceriodaphnia sp*, **E**) *Moina micrura*, **F**) *Moina sp.*, **G**) *Oncaea sp.*, **H**) *Naulius larva of . Cyclopoid*, **I**) *Acartia sp*, **J**) *Mesocyclops sp*, **K**) *Microcyclops varicans*, **L**) *Diaphanosoma sarsi*

2.6 Predator–Prey Interactions: Role of Trophic Polymorphism

Prey organisms are mostly endowed with polymorphic pattern of traits termed as antipredator defensive traits, for becoming inedible and thereby to escape from the predation pressure. This is evident from the ability of phytoplankton to avoid zooplankton predation by means of colony formation, while zooplankton exhibiting cyclomorphosis functions to deter predations of fish and other aquatic fauna (Lass and Spaak 2003).

In contrast, fish predators displaying polymorphism in behavioral and morphological traits, mostly associated with feeding habits, are referred to as trophic polymorphism (Smith and Skulason 1996). Intraspecific variation in feeding traits leads to discrete variation in species trophic niche through functional differences of aquatic ecosystems, because mainly of genetic mechanisms determining their polymorphism. The intraspecific functional diversity of fish predators alters aquatic community structure and ecosystem processes.

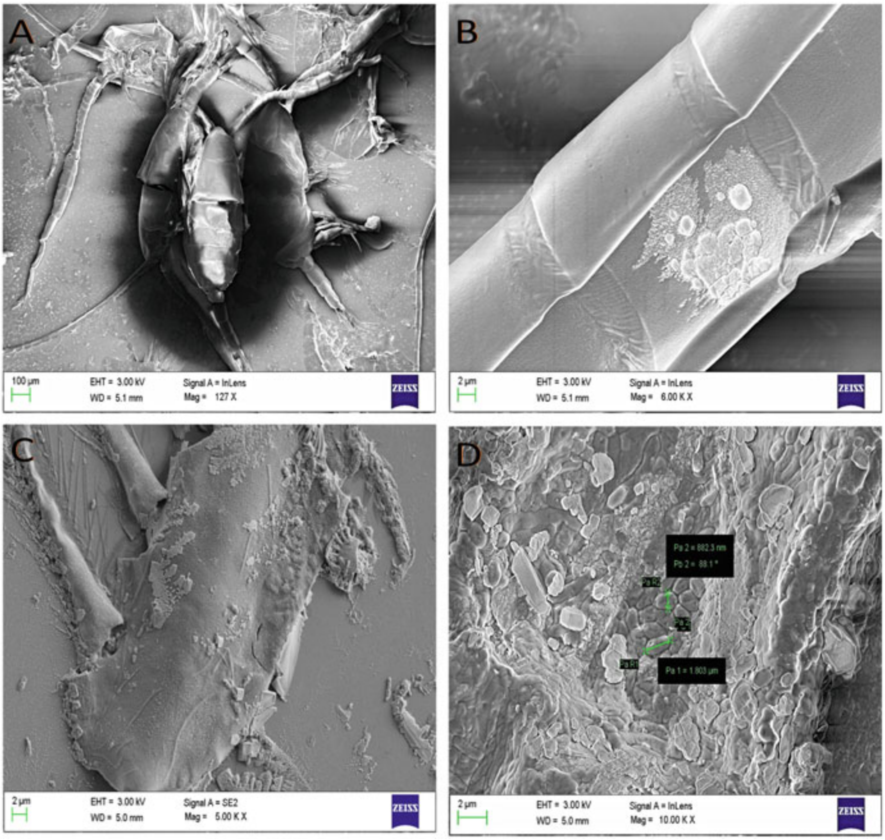

Fig. 2.4 Bacteria–zooplankton association and interaction, a new approach for biodiversity research (Midya et al. 2019)

Finally, the environments after being modified by a predator's functional diversity, trigger the evolutionary diversification of aquatic biota through eco-evolutionary feedbacks.

2.7 Phenotypic Polymorphism: In Aquatic Ecosystems

Phenotypic polymorphism is defined as that condition where two or more clearly different phenotypic traits coexist within the same population of a species, representing and strengthening the existing taxonomic phenomenon and interpretations for a variety of taxonomic groups from prokaryotes to higher vertebrates. This unique phenomenon is noted in traits related to prey size selectivity or prey species-specific foraging efficiency among several aquatic organisms (Robinson and Gessner 2000). The polymorphic phenotypes are manifested by behavioral, morphological, physiological, and life history traits (Gross 1996).

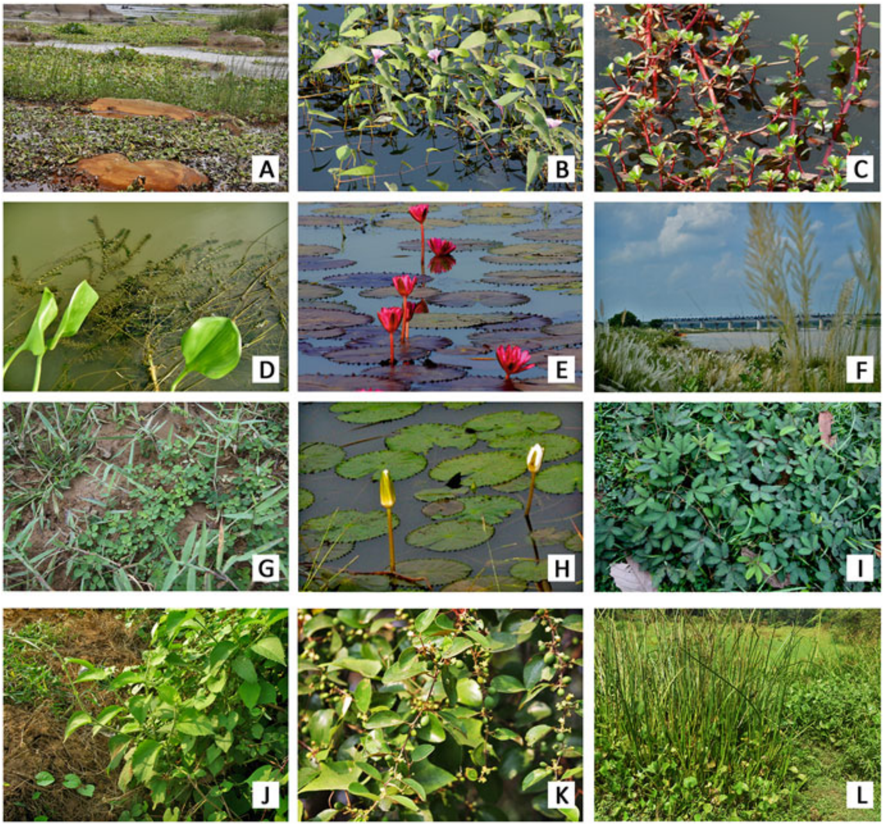

Fig. 2.5 Representative forms of diversity of some major macrophytes **A**) *Eichhornia crassipes (Mart .) Solm.*, **B**) *Ipomoea sepiaria Koenig ex Roxb.*, **C**) *Jussiaca repens L*, **D**) *Blyxa octandra (Roxb.) Planch ex Thw*, **E**) *Nymphya rubra Roxb . ex Andrews*, **F**) *Saccharum spontaneum L.*, **G**) *Marsilia crenata*, **H**) *Nymphia Pubescens Willd*, **I**) *Mimosa pudica*, **J**) *Tragia involucrate*, **K**) *Zizyphus mauritiana L*, **L**) *Eleocharis plantaginea R. Br*

2.7.1 Trophic Polymorphism and Adaptive Divergence

As an efficient way to reduce intraspecific competition, the aquatic faunal components, especially fishes, have been found to make partition of their resources by changing foraging behavior to occupy alternative empty niches as the other existing niche are occupied and by saturated due to the increase of population. This flexibility in foraging behavior is thought to be the first step of niche specialization (Bolnick et al. 2003). The genetically inherited foraging behavior in the progeny enable to harvest targeted specific resource and their utilization through behavioral specialization, which have been facilitated by the subsequent morphological and physiological adaptations to cope up with the changing ecological conditions (Sacotte and

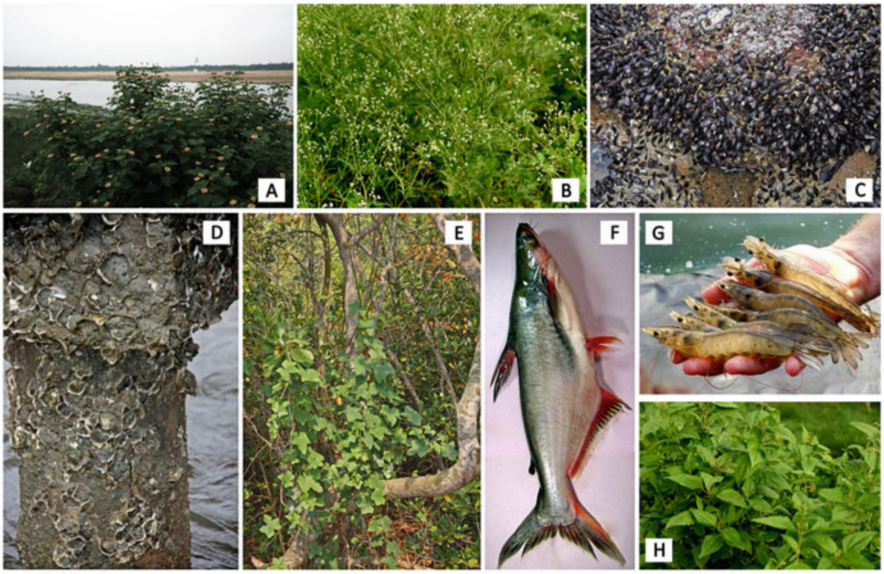

Fig. 2.6 Representative forms of diversity of some bioinvasive species **A**) *Lantana camara*, **B**) *Parthenium hysterophorus*, **C**) Bivalvia (*Enigmonea aenimata*), **D**) Bivalve (*Cassostrea madranenses*), **E**) Climber-*Coccinia grandia*, **F**) Pangas -a fast growing predator fish, **G**) White Vannamei shrimp, **H**) *Ageratus conyzoids*

Magnan 2006). Such a phenotypic adaptation in turn enables each individual of the population to be competent enough for the effective utilization of different resources, thereby paving the way for disruptive selection within the population (Knudsen et al. 2010). Development of reproductive isolation because of sexual selection lead to develop such a situation which causes adaptive divergence and subsequently results in ecological speciation (Seehausen et al. 2008).

Marked interspecific diversity of trophic niches and morphology as found in African cichlids is explained as resource partitioning mediated evolutionary consequence among individuals belonging to a colonized population (Bootsma et al. 1996; Genner et al. 1999).

2.8 Ecological Services of Biodiversity

The **Millennium Ecosystem Assessment** (**MEA**, 2005) defined ecosystem services as the benefits that people obtain from the functioning of ecosystems. Ecological services denote the contribution of nature to a variety of "goods and services" to mankind in respect of economics and ecology.

Biodiversity representing a major share of the structural components of global environment renders valuable ecological services to all the ecosystems of the earth

Fig. 2.7 Representative forms of diversity of some major aquatic insects: **A**) Dragon fly: Order Odonata; Family: Labellulidae; Erythemis sp; **B**) Larval form of aquatic coleopteran insect; **C**) and **D**): Order: Hemiptera: Family: Belostomatidae; *Diplonychus annulatus*; **C**) Dorsal view and **D**) Ventral view; **E**) and **F**) Water scavenger coleopteran beetles; Order Coleoptera: family:

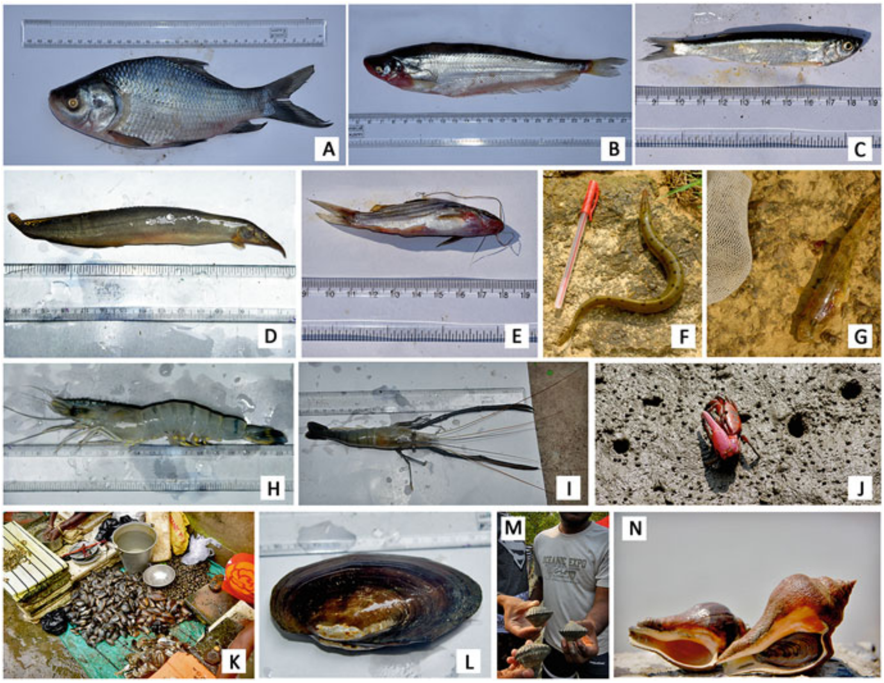

Fig. 2.8 Representative forms of diversity of some major shellfish and finfish. **A**) *Catla catla* **B**) *Ompok pabda* **C**) *Salmostoma bacaila* **D**) *Macrognathus pancalus* **E**) *Mystus cavasius* **F**) *Anguilla bengalensis* **G**) *Glossogobius giuris* **H**) *Paeneus monodon* **I**) *Macrobrachium rosenbergii* **J**) *Uca acuta acuta* **K**) *Belamia bengalensis* **L**) *Lamellidens marginalis* **M**) *Anadara granusa* **N**) *Predatory estuarine gastropod*

for their proper functioning including rivers and its associates basins, floodplains, streams, and other wetlands (Hanson (1998); Hortle (2007); Barrett et al. (1997); Bishop (1993); Butchart et al. (2012); Lawrence and Caldwell (1987); Pejler (1977); Schneider and Sharitz (1988); Sharma et al. (1999a); Sharma et al. (1999b); Siqueira

Fig. 2.7 (continued) Hydrophilidae: Hydrophilus sp.; **E**) Dorasl view and **F**) Ventral view; **G**) Water scorpion; Order Hemiptera; Family: Nepidae;. Laccotrephes sp; **H**). Predaceous diving beetle: Order Coleoptera; Family: Ditiscidae; Hydaticus sp.; **I**). Water bug: Order Hemiptera ; Family : Belostomatidae ; Appasus sp, **J**) Water Scorpion ; Order : Hemiptera : Family Nepidae ; Laccotrephes sp; **K**). Water Strider : Order : Hemiptera : Family : Geridae ; Gerris sp; **L**). Soil Inhabiting ; Order Coleoptera : Family Curculionidae ; Coceotrypes sp **M**). +**N**) Predacious Diving Beetle ; Order Coleoptera : Family : Dytiscidea ; Cybister sp : M) Dorsal view and **N**) Ventral view; **O** +**P**) Water scavenger beetle; Order : Coleoptera ; Family : Hydrophilidae : Hydrophilus sp; **O**) Dorsal side and **P**) Ventral side; **Q**) Water scorpion : Order Hemiptera : Family Nepidae ; *Laceotrephes griseus*; **R**) Water strider : Order Hemiptera ; Family : Gerridae ; *Limnogonus nitidus* **S**) Soil Termite : Order Isoptera : Family : Termitidae; Odontotermus sp.

et al. (2015); Strauss et al. (2006). Large-scale declines in global biodiversity and the widespread disruption of ecosystem services have led to realize the urgent necessity to safeguard both by integrating different aspects of biodiversity-derived ecosystem services of the ecozones into the design of conservation interventions. (Balvanera et al. 2001; van Jaarsveld et al. 2005; Chan et al. 2006, Chakraborty 2017). However, the degree of such services rendered by each species still remains to be unknown (Myers 1996; Balvanera et al. 2001). Targets should be supported by the identification and application of indicators to estimate the value of ecosystem services which should reflect the urgency of the threats because of the interdependencies of targets. (Perrings et al. 2011). Ecosystem services rely more on functional traits of those species composing the structure of the ecosystem instead of the taxonomy of species (Barrett 1994; Solan et al. 2004; Butchart et al. 2010; Kattge et al. 2011).

2.9 Ecosystem Engineers in River Ecosystem: Ecological Service Providers

Sedimentary environments represent dynamic habitats in which the sediments, the fundamental constituent of the habitats of organisms, are continually structured by both the prevailing physical and biotic forces. Different bio–geo–physicochemical activities, of different forms of biodiversity components, have shown to result in alteration of the textural components of the sediments (sand to mud), biotic structuring of the habitat by settlement, growth and development, burrowing, tube building, defecation and secretion often is significant (Rhoads and Boyer 1982; Woodin 1999; Gilbert et al. 2007). The main actors in this process are represented by a number of aquatic biota such as microbes playing active roles in recycling of nutrients; macrophytes in arresting soil erosion; bioaccumulation of toxic substances are also used for generating nutrients by acting as the materials to be decomposed; phytoplankton for primary production by fixing solar rays and converting the kinetic energy to static ones with the generation of oxygen; fishes act to remove detritus and other decomposing products by feeding, and benthos untertake the bioturbation process, a biogenic activity for cycling of trace metals, nutrients, and pollutants, (Chakraborty 2017). Bioturbators include a wide array of benthic fauna like crustaceans (such as burrowing crabs and shrimps), polychaete worms, mollusks, echinoderms, sipunculans, cnidarians, Priapulida, and other meiofaunal organisms.

Different bioturbation activities, such as burrow and mound construction, ingestion, and egestion of particles during foraging, food caching, prey excavation, wallowing, etc., influence considerably the ecodynamics of both terrestrial and aquatic environments (Fager 1964; Aller 1988; Aller and Aller 1998; Cadee 2001; Chakraborty 2017). Biogenic structures also alter the ability of individuals to burrow through the sediment. All those biogenic modifications have appeared to determine the species composition, distribution, and community interaction patterns of the infaunal communities. Defecation by large infauna tends to impose negative impacts on other infauna, leading to reduce growth rates, decrease the recruitment process, and increase emigration activities. The patterns of distribution and abundance of organisms are frequently correlated with different grades of habitat heterogeneity.

Changes in habitat heterogeneity may be attributable to changes in the abundance of physical and biogenic structures. Bioturbation, the disturbance of sediment layers by biological activity, imparts significance effects on the bottom sediments of all aquatic systems. By an array of benthic animals such as worms, mollusks, insects, crustacea, etc. by resuffling the sediments and also by consuming organic matter trapped between sediment grains.

2.9.1 Roles of Aquatic Macro-invertebrates in Determining Biogeochemical and Nutrient Cyclings

In order to chalk out strategies for the conservation and management of biodiversity, much emphasis is being laid on ecological principles and concept, especially involving an in-depth understanding of trophic relationships (Balmford et al. 2002). Millennium Ecosystem Assessment (2005) has concluded based on a recent global analysis that half of the world's ecosystem services are being used unsustainably due to the lack of attention towards the threats and elimination of the ecosystem service providers. Macro-invertebrates being a major biotic component in any ecosystem govern key ecological processes, especially in the biogeochemical cycle of sediment, which in turn help in releasing nutrients, consuming oxygen, and utilizing organic matters by their biological activities.

Nitrogen present in organic materials is transformed by bacteria into free ammonium, nitrate, or gaseous nitrogen through three interlinked processes: (**1**) ammonification, (**2**) nitrification, and (**3**) denitrification. Sediments loaded with toxic substances are transformed into anoxic sediment at certain ecological conditions and depth in the bottom muddy sediment mangrove mud and the sediments around the burrows of benthic crabs in mangrove ecosystem.

The burrows formed by the tunneling activities of mud crabs act as the primary sites for the importing of ammonium and exporting of both and gaseous nitrogen from the mangrove ecosystem. The bacteria residing on the wall of the crab's burrows rapidly utilize the oxygen for the purpose of litter decomposition from the incoming burrow water and thereby convert the toxic mud layer around the burrow openings into much thinner anoxic layer at the visible mud surface. Therefore, burrows of crabs can be considered as the primary site for the release of ammonium into the surrounding mangrove ecosystems. However, the sediments loaded with detrital particles around the burrow openings seem to offer ideal conditions for both ammonium-oxidizing (nitrifying) bacteria and nitrate-reducing (denitrifying) bacteria leading to develop tight coupling of nitrification and denitrification (Chakraborty 2017).

Through this interaction, crab burrows can effectively remove nitrogen from the aquatic ecosystem in the form of gaseous nitrogen (Holmboe et al. 2001). Humans have always depended on nature for environmental assets like. Human domination of the biosphere, especially in search of ecological goods and services such as clean water, pure air, favorable nutrient cycling, and soil formation has considerably altered the composition, structure, and functions of ecosystems (Vitousek et al. 1997; Palmer et al. 2005). A recent classification scheme on ecosystem services divides them into four categories: provisioning services (food, fuel, fiber, timber, etc.), regulating services (climate, flood control, etc.), supporting services (pollination, soil formation, and other ecological properties and processes on which biodiversity and other ecosystem services depend), and cultural services (recreational, spiritual, and aesthetic values) (Millenium Ecosystem Assessment 2003).

2.9.2 Economic Valuation: An Economic–Ecological Coupling Assessment

Economists and ecologists are just beginning to credibly assign economic value to ecosystem processes and the mode of transformation and conversion of these processes into marketable commodity having the potential of tradable services. Economic valuation does not attach importance of the need to cover values for all components of ecosystems, but attempts are being made to simply capturing the unattended and overlooked areas for assigning values.

The valuation of ecosystem services in turn facilitates to take up cost–benefit analyses giving due importance to changes in ecosystem services to human welfare and also to find out and judge alternative pathways of development to keeping pace with ever-expanding human populations (Chakraborty et al. 2014; Chakraborty 2017). **The Millennium Ecosystem Assessment** (2005) has identified ecosystem functions with the provisions for ecosystem goods (food, water, fuel, fiber) and services (prevention of soil erosion, flood control, recreation, providers of spiritual values, soil formation, nutrient cycling, production of oxygen from photosynthesis, etc.).

Ecosystems with low diversity can also provide considerable ecosystem services, and even modest losses of biodiversity may not substantially reduce ecosystem services (Chakraborty 2017).

2.9.3 Ecosystem Management: Roles of People's Participation

Economic and ecological services of biodiversity in ecosystem management are based on understanding how natural systems work and how human activities may influence these systems. Management is also about identifying the values that are required to be protected in respect of economic costs or gains of preservation. This has necessitated for an ecological and economic evaluations of ecosystem goods and services, recognizing both as the most important components in formulating practical eco-management policy.

Biodiversity components play a fundamental role in providing the basis for all ecosystem goods and services, although detailed understanding of the complex underlying mechanisms is still limited. Some general aspects of biodiversity do, however, link directly to goods and services. Perception of local peoples during the last several decades are now being utilized for having a knowledge base on the trend of change of biodiversity and functional relationships between organisms and fluxes of energy or matter in soft sediments so that all those baseline information can be utilized to develop systematic and sustainable conservation strategies (Patra et al. 2005; Mishra et al. 2009). The demand of the time is to bridge the gap between the spatial and temporal variability in respect of the distribution of species and their behavior by gathering information on the transport and transformation of chemicals within the sediment and across the sediment–water interface (Dye and Lasiak 1986). Interactions between bioturbation and mineralization processes in sediments depict highly nonlinear configuration after being characterized by the influence of strong feedback loops among different species of macrobenthic fauna, their food, and their chemical environment (Huhta 2007; Gray and Elliott 2009).

In such context, the functional role of benthic fauna is not only to sustain the balance in the ecosystem functioning but also to ensure livelihood generation by way of ecological services.

2.9.4 Ecological Services of Freshwater Rivers

The biodiversity components of freshwater riverine system are supposed to render valuable ecological services by virtue of their position and functional roles in the food chains and food webs of the lotic ecosystem.

These services include stabilization of the sediments alongside enriching the biodiversity by facilitating the development of conducive ecological condition for the settlement and flourishing of biota such as algae, microbes (bacteria and fungi), meiobenthos, etc. because of the pumping of sufficient air and water through the formation of innumerable pores, tubes, burrows, etc., reshuffling of nutrients and sediment texture by bioturbation activities, releasing of millions of larvae in the form meroplankton in the aquatic subsystem and thereby providing live food to the fishes, and biotransformation of organic chemicals into inorganic and vice versa. All of these have contributed in a holistic manner to the sustenance of mangroves and their associated biodiversity components which in turn serve a number of ecological services.

Alongside providing clean air and water, other ecological services rendered by riverine ecosystem include protection from flood, cyclones, and other natural disasters, providing drinking and irrigation water and ground freshwater supplies, arresting soil erosion, recycling nutrients, filtering pollutants, regulating water flows and supplies, maintaining biodiversity, and contributing to carbon sequestration Wallace et al. (1982); Wallace et al. (1996); Ward and Stanford (1983a); Wardand Stanford (1983b); Webster and Meyer (1997).

2.10 Connectivity in River: Importance in Ecology and Biodiversity

Although connectivity between homogenous habitat patches of terrestrial ecosystems have been focused on conservation research, its applicability in riverine ecosystem has not been established a few decades back. However, during the early 1980s, the term **connectivity** has started to replace the terminology **river corridors** (Amoros and Roux 1988; Pringle 2006) in order to depict the spatial connections within river systems (Ward 1997; Wiens 2002).

Knowledge pertaining to the assessment of the roles of connectivity in terrestrial ecosystems started to be transferred and applied to aquatic ecosystems. Rivers having their unique characteristics exhibit certain structural manifestations, which have granted this ecologically interesting landscape a special position in connectivity conservation:

1. River systems representing both habitat and migration corridors (Ward 1989; Wiens 2002) are distinguished by their inherent water-mediated connectivity.
2. Connectivity operates in both temporal and spatial dimensions: longitudinally from headwaters to the extreme end part of the downstream, laterally from the main river bed to floodplains, and vertically through a stratified layers of river bottom towards the hyporheic interstitial and the groundwater (Ward 1989; Jungwirth et al. 2003).
3. Terrestrial connectivity emphasizes on interactions of homogenous patches, while in aquatic ecosystem, diverse habitat patches are required to enable certain species to complete different stages in their life cycle (Jungwirth et al. 2003).

Vannote et al. (1980) developed the **River Continuum Concept (RCC)** to highlight the longitudinal, biocoenotic change (expressed as production/respiration ratio) in relation to hydro-morphological conditions. **RCC** only focuses on the downstream succession of feeding types, whereas consideration of the lateral and vertical dimensions is ignored.

Owing to some limitations of **RCC**, another concept, named as **extended serial discontinuity concept (ESDC)**, has been developed by Ward and Stanford (1983, 1995b) emphasizing on the longitudinal variation in four dimensions, alongside incorporating of anthropogenic alterations. Since the **1980**s, ecologists started to differentiate ecological and connectivity-related components of landscape and riverscape as both being the habitats of organisms, the populations of which are potentially connected by four dimensionality (Ward 1989, 1997). The former concept put more stress on the underlying scientific principles pertaining to metapopulation ecology highlighting the impacts of limited genetic exchange between populations (Moilanen and Hanski 2006).

2.11 River Fragmentation: Impact on Biodiversity

Habitat fragmentation has been posing real threats to diverse forms of rivers in varied ways (Dynesius and Nilsson 1994; Nilsson et al. 2005). More than **58, 400** large dams (**>15 m** in height) have been constructed across the globe in order to render services mainly for the benefit of human being in respect of irrigation, hydropower production, water supply, and flood control (ICOLD 2016). Construction of these dams has resulted in fragmentation of a considerable number of large rivers (more than **60%** present in the world) having a length of greater than**1000 km** (**WWF** 2006).

As migration opportunities of fish in stream networks are very much limited, disconnections within the running water bodies have aggravated the situation to become more challenging and difficult for fish to avoid such constrains (Fagan 2002; Fullerton et al. 2010). Such habitat fragmentations are being considered as a major reason for the loss in global aquatic biodiversity to a greater extent (Pringle et al. 2000; Rosenberg et al. 2000). Around **10, 000–20, 000** freshwater species have already become extinct or at the risk of extinction throughout the world (Vörösmarty et al. 2010). In the context of river fragmentation, one pertinent aspect in respect of riverine biodiversity is metapopulation.

Metacommunity is designated as a set of local communities which are linked by the to-and-fro movement and dispersal of different interacting species, whereas biotic communities are formed by the interactions within a single patch or of local habitat of all individuals belonging to the resident species (Wilson 1992). Metacommunities can reorganize the relationships among different constituent populations at various scales, in the context of changing environmental conditions (Leibold and Miller 2004)

Habitat fragmentation poses an inherent problem for so many aquatic fauna, especially fishes for biologically programmed migration synchronizing with the change of seasonal ecological parameters. In most all ecosystems including river ecosystem, metacommunity dynamics have been regulated by the process of habitat fragmentation and the steady dispersals among the biotic components of the biotic communities experience hindrance by increasing isolation and loss of patches.

A recent study (Halder and Chakraborty 2015) focusing mostly freshwater zooplankton as the prime biotic component to analyze metacommunity structure which has been shaped, structured, and influenced by habitat fragmentation in two freshwater wetlands of Midnapore (West) district, West Bengal, India, characterized by comparable ecological conditions. An attempt was also made in the same study to compare effects of spatial connectedness, habitat fragmentation, and seasonal fluctuations of environmental parameters along with seasonal variability in the assemblages of aquatic vegetations (provider of nutrition, protection, and shelter) on rotiferan community, especially during the contrasting ecological conditions (lean or flow period), influencing species dispersal. The dispersal ability of the organisms among different habitat patches within the metacommunity depends on the distance and ecological conditions of connections among patches (Shurin et al. 2000). This study has recorded additional **22** rotifer species of the earlier documented list of freshwater rotifers from this eco-region (Pradhan and Chakraborty 2008; Halder et al. 2007).

However, this diversity of rotifers is much less in comparison to the earlier record of the rotifer diversity from the several wetlands of northeastern part of India (Sharma 2005; Sharma 2010) and from a number of the freshwater rivers of the South West Bengal, India (Pradhan and Chakraborty 2008). The diversity, species composition, and percentage of surface coverage of macrophytes have appeared to be important density-dependent factors determining the density and diversity of aquatic invertebrate faunal components.

Considering the ecological roles of macrophytes, it can be interpreted from the research findings of this study that habitat preference of some species of rotifers is influenced by macrophytes instead of the their ability for dispersal, colonization, and establishment to the new habitat as the habitat tends to attract and select the organisms which will thrive (Walsh et al. 2007).

Contrarily, some species are known to have high habitat selectivity which are strongly influenced by cumulative impact of so many ecological factors of a specific habitat and season (Kaya and Raynal 2001a, b; Joniak et al. 2007, Wallace et al. 2005). This has been proved in the present research study too, where season has been found to be a major factor in determining the bulk species of a habitat. Further, macrophytes have been found to influence the colonization of some zooplankton species unique to a particular local habitat.

Owing to the discontinuity of water flow between sub-sites under the main study areas, among zooplankton communities of fragmented sub-sites for both study sites exhibited least similarities during postmonsoon period. Based on a similar study, Fontaneto et al. (2008) recorded low species diversity but high habitat selectivity of Bdelloids spp. which enabled them to hypothesize that with less and rare dispersal ability, colonists fail to become established as habitat availability tended to limit their chance for settlements..

In this study, zooplankta inhabiting at **Study Site 1** displayed substantial dispersal abilities, while the zooplankta residing at **Study Site 2** showed negligible power of spatial dispersal within the studied metacommunities of contrasting wetlands because of effective fragmentations, which also corroborates the findings of Cottenie and De Meester (2003), Declerck et al. 2007; Declerck et al. (2011). Connectivity between subcomponents of present study, probably by passive water movement in a complex manner, is found to be similar to the case of large lakes, which corroborates the findings of Leibold et al. (2004).

Therefore the present study emphasizes the actual heterogeneity in spite of apparent homogeneity of selected water bodies. Regional species diversity and density patterns across months showed distinct trends with nearly synchronized peaks for rotifers, copepods, and cladocera together in both sites **(Figs. 2.2, 2.3 and 2.4**). Studying the distribution of zooplankton species on the basis of physico-chemical parameters revealed one strong cluster for each site.

In spite of the abovementioned variations in the individual site, the zooplankton communities of both sites have been found to converge on a similar assemblage of taxa annually at regional scale (Table 2.8). Cadotte (2006) showed that dispersal affects richness at the local community scale, but not at the metacommunity scale. The research outcomes of a recent study by Halder and Chakraborty (2018) have revealed that individuals belonging to the different species of zooplankton exhibited movement in between several isolated water bodies formed during summer months because of high temperature-mediated evaporation coupled with least occurrences of precipitation via both direct connections such as water channels or floodings and overland dispersal in order to ensure connections and mixing of populations within the metacommunity. These observation also corroborated the earlier similar studies (Michels et al. 2001 Cáceres and Soluk, 2002; Cohen and Shurin, 2003), Alongside testing the existing hypothesis of **community-wide character displacement (CWCD)** (Leibold et al. 2004), based on the outcomes of this study, it has also been hypothesized that local communities are structured both by local interactions such as competition, predation, different prevailing ecological variables, and regional interactions involving dispersal of individuals between habitats highlighting spatial configuration of dispersal pathways. Different perspectives of the studies on metacommunity can strongly modify the ways by which more than one adjoining communities are regulated, and their structures are determined by the prevailing environmental conditions (Cottenie et al. 2003).

This study had also corroborated the hypothesis of **CWCD** stating that locally coexisting species communities within each site are less similar to each other than random aggregate draws from the two regional water bodies. Wallace et al. (2005) stated that communities vary widely among different habitats, which appears to be due to the influence exerted by the local edaphic conditions.

In the present study, it was also found that constituent species tended to fluctuate within a wetland enjoying similar ecological conditions that prompted to develop another hypothesis that stronger partitioning between adjacent local habitats led to more heterogeneity between inhabiting plankton populations, making seasonal influence secondary. Contrarily, even slight connectivity was supposed to be sufficient to homogenize the majority community of a wetland (enabling successful intrasite colonization). This highlighted season as a primary factor which directly or indirectly governed the regional metacommunity.

2.12 Consequences of Species Loss for Ecosystem Functioning: Meta-analysis Approach

Research studies pertaining to the diversity, distribution, and density of species in relation to pronounced ecological variables in nature (Whittaker 1975), and to species and community interactions (Krebs 1972), have had considerable acceptance in the field of aquatic in ecology.

In view of prospective threats generated because of environmental changes on the species for their probable extinction, researchers became interested to undertake quantitative assessment of the impact of a change in species diversity which serve as the indicator of the changes of environmental factors and species interactions. Researches during the last few decades have been oriented to focus on comprehensive quantitative assessment on the average and random reductions in diversity of species which in turn result in the reductions of ecosystem function (Balvanera et al. 2006) This meta-analysis evaluating the effects of biodiversity by deducting correlation coefficients in between biodiversity-related attributes (usually species richness) and data generated out of representative response of community, and the constituent populations level, reveals the significant determining roles of several ecological factors.

2.13 Functional Diversity and Biodiversity

In the early **1990**s, foci on biodiversity research were shifted from evaluating the effects of ecological variables on biodiversity to assessing the roles of biodiversity in shaping and directing ecosystem processes (Naeem et al. 2002) which subsequently led to developing hypotheses (Schläpfer and Schmid 1999) that collectively elucidate the relationship of different biodiversity components with functional aspects of ecosystem (Schmid, 2002a, Schmid et al. 2002b, Raffaelli 2004). The emerging ecological concept pertaining to biodiversity–ecosystem functioning (**BEF**) (Loreau et al. 2001, 2002) impelled effectively because of prospective anthropogenic global changes which have been proved to be an effective contributor for the loss of biodiversity in most ecosystems, thereby resulting in negative ecological consequences leading to profuse harm to human well-being (Vitousek et al. 1997, Sala et al. 2000, Díaz et al. 2006, Fischlin et al. 2007).

This has simultaneously been observed that increased species richness enhances the performance of entire communities, but reduces the average contributions of individual species. Responses of biodiversity effects on the ecosystem level (abiotic) always tend to be positive, but not as much as community-level responses due to the effects of biodiversity (Ward and Stanford (1983a); Ward and Stanford (1983b); Webster et al. (1995); Wootton (1998); Wu and Loucks (1995)).

2.13.1 Significance of Functional Diversity: Justification from the Species–Ecosystem Relationships

Presently functional diversity being a component of biodiversity takes into consideration the kind (nature and types), places, and purposes for exploiting resources by the organisms (Tilman 2001, Naeem and Wright 2003, Hooper et al. 2005, Petchey and Gaston 2006). All those attributes are considered as integral components of functional diversity. Since the functional activities of organisms, summerising of organisms ultimately shape the ecosystem processes, summarizing outcomes of such activities as help measuring the diversity which in turn throw light with regard to the operating ecosystem processes (Tilman 2001, Hooper et al. 2005).

In such context, functional diversity forms the necessary linkages among morphological, physiological, and phenological variations of different individuals under a species to the levels of ecosystem processes and patterns in such a way so that a species can counterbalance the damages caused by the loss of another species in an ecosystem. As ecosystems are constituted by several functionally similar (belonging to same trophic level) and dissimilar species (belonging to different trophic levels), each of the similar species has the access to the same pool of resources. Therefore, loss of one species will not cause any reduction in the use of that resource pool, as the other species that are present in the same ecosystem will accordingly simply increase their use of that same resource (Mishra et al. (2009); Nelson (1984); Patra et al. (2004); Patra et al. 2005; Pradhan and Chakraborty (2006)).

Thus functional diversity refers to a measure of highlighting the underlying scientific principles of ecological interactions among different species constituting the biotic community in order to provide a general approach for mounting characteristics of individuals to species interactions in a biotic community and then to ecosystem processes. All those functional attributes have recognized functional diversity as a potentially powerful concept in ecology which is in need of both qualitative and quantitative evaluations to understand multidimensional pathways that operate in between biodiversity and ecosystem (Cetra and Petrere 2006; Chakraborty 2018; Dauwalter and Jackson 2004; Day 1889); Flecker and Townsend 1994; Jayaram (1999); Jennings et al. (1999).

2.13.2 Assessment of Functional Diversity

Quantifying of functional diversity is needed for examining the uniqueness of some species based on distinct especially in respect of their functional relationships with the environment and also to assign some species to suitable place as functional groups (ecological guilds) depending on all these characteristics (Root 1967).

However, the major demerits with this method are related to all linking and assigning the species to respective groups which ultimately determines the number of functional groups and the average number of species in a functional group. The functional diversity is measured by the functional group richness which refers to the number of functional groups represented by the species in a local assemblage of different species (Root 1967, Martin Solan et al. 1992 Elena et al. 2006).

In view of the above, the functional groups encounter a number of problems:

Firstly, any interspecific differences within a group should be ignored. In the event of development of continuous variation, the quantum of variation that is ignored by functional group richness could be large. Since many important functional traits are continuous, this is a large problem. Even the discontinuous traits, like N-fixing, are in fact continuous at some scale, with the efficiency of nitrogen fixation which tends to vary at different soil conditions (Vitousek et al. 2002).

Secondly, the manifestation of actions of functional group richness depends considerably on the number of well-defined functional groups (Fonseca and Ganade 2001 Petchey and Gaston 2002a). Functional groups constituted by fewer number of species impart strong effects of species richness (and extinctions) on functional diversity, which in contrast to functional groups, accommodating many species per functional group, demonstrate weak effects of species richness on functional diversity.

Thirdly, no objective method exists for deciding on the number of species required to form different functional groups. Besides, the number of functional groups, and number of species constituting specific p functional group, and the mode of the effects of species richness and extinction on functional group richness have appeared to be arbitrary.

Finally, existing research evidence points out that some targeted and focused assignments of species to functional groups are more effective than random assignment of species to functional groups. In particular, higher correlations between functional group richness and ecosystem processes with random assignment of species groups were recorded in a well-studied grassland plant ecosystem (Petchey 2004, Wright et al. 2006).

2.14 Differences Between Different Biodiversity Measures: Effects of Species Richness on Functional Diversity

Biodiversity can affect ecosystem processes by several ways (Tilman 1999b, Chapin et al. 2000), because species composition and richness are changed along with the changes of biodiversity. For example, an invasion adding a novel species with a novel identity through invasion change species composition of already settled biotic community and also tend to increase species richness by adding more species. However, lots of conflicting opinions come up on the mode of impacts of the introduced species regarding whether the effects of the identity of a novel species is more important or the effects of having one more species is with higher significance (Loreau et al. 2001).

Functional diversity is a vital component of research about the functional consequences of biodiversity (biodiversity–ecosystem functioning) in comparison to phylogenetic or taxonomic diversity. Indeed, the **Millennium Ecosystem Assessment** (**MEA**) (2005) has stressed upon the functional roles of species instead of just describing a species based on morpho-anatomical excellences. Therefore, it can be concluded that developing relevant concepts and related hypothesis to explain functional diversity based on the understanding of the natural histories (traits) of species and their mode of interactions with the prevailing environmental conditions can become an important prerequisite for undertaking effective management and conservation to ensure steady supply of ecosystem services.

2.15 Biodiversity–Ecosystem Functioning (BEF)

The erosion of biodiversity at an alarming pace due to multitude of anthropogenic activities can be explained by a synthesis of community and ecosystem ecology (Wilson 1992) which was thought to block the smooth delivery of ecosystem services (Daily 1997).

Biodiversity–ecosystem functioning (BEF) research being a core concept of this emerging synthesis is concerned in assessing the magnitude of relationship in between biodiversity and ecosystem stability. Isolating the functional effects of species richness and diversity from just the mere species composition within a community has been considered as the main aim of **BEF** research and this has emerged based on the well-established fact that the mean magnitude of directional changes of ecosystem properties is enhanced by species richness (Hooper et al. 2005; Balvanera et al. 2006; Cardinale et al. 2006), whereas the ecosystem stability remains equivocal after being influenced by species richness (Hooper et al. 2005).

2.15.1 Theory Linking Biodiversity and Ecosystem Stability

Different theories have tried to interpret the possible bondages in between species richness and the mode of oscillations of different structural components of biotic community representing different ecozones at varied time scales in order to generate a variety of possible explanatory mechanisms (Doak et al. 1998; Cottingham et al. 2001, Loreau et al. 2002). Analyzing the research information generated out of such studies, those theories point out that a reduction in the variability within a community results in an increased diversity which consequently led to develop the concept of **statistical averaging** (the sum of many randomly and independently variable items becomes less variable than the average item). The main force behind such effect lies on the trend of the variances of population scale with their means (Tilman et al. 1998) and the prospective relationships of the mode of fluctuations of the evenness of species' abundances (Doak et al. 1998; Tilman et al. 1998). The consequences of the process of species fluctuations are reflected in another stability mechanism which is closely related to the concept **of statistical averaging, the insurance hypothesis**, which advocates that interspecific niche differentiation causes species to respond in diverse ways to the other changes in the environment and that this differential response can produce compensatory dynamics among species, buffering the impact of environmental changes (McNaughton 1977; Walker 1992; Naeem and Li 1997). The insurance hypothesis mostly relies on functional redundancy, which is an established concept pertaining to the ability of constituting species within the same functional group to replace each other without causing any ecological consequences in respect of ecosystem functioning.

The stabilizing role of such mechanism further relies on the responses of different species within functional groups, and exhibiting variety of responses by different constituent biotic components, the concept of **functional response diversity** emerged (Lavorel and Garnier 2002; Elmquist et al. 2001, 2003).

2.15.2 Diversity and the Stability of Ecosystem Services: Case Studies

A number of research studies have tried to bridge the gap in between empirical and theoretical interpretations and the practical application-based research analysis on the human-mediated ecological alterations and the quantum of disruption in the stability of biodiversity and the provision for ecosystem services.

Case studies dealing with two ecosystem services, first pollination and second fisheries yield, can be cited as examples which advocate that species diversity can influence the stability of ecosystem service provision. Pollination, being one of the one key ecosystem service providers, has received attention within agricultural landscapes. Kremen et al. (2002, 2004) showed that intensive farming practices and a reduction of the proportion of natural habitats usage negatively affect the diversity of pollinators and render temporal stability of melon pollination. Agriculture sites with high pollinator species richness provided more stable pollination services over time than sites with low species richness because of asynchronous fluctuations in the populations of pollinators from one year to the next. The role of species richness in spatial stability of pollination was demonstrated in coffee plantations too, where: greater pollinator diversity, is affected by local plant diversity, and light availability, regional factors (isolation from natural habitat) and reduced spatial variation in fruit set between coffee plants (Klein et al. 2003a).

Research studies on fish and fisheries, being considered as an important source of chief proteins for most people all over the globe, especially in the developing countries, have generated research information on the collapsed fisheries in a region which was negatively related to its fish taxonomic diversity (Worm et al. 2006).

Furthermore, it can be inferred that the likelihood of recovery from fisheries collapse was positively associated with species richness across large marine ecosystems. Causality is difficult to infer from this correlative approach, but the results support the supposition that diversity increases both resistance to ecological perturbations and recovery from overexploitation (Harris and Heathwaite (2005); Hughes et al. 2002; Schubauer and Hopkinson (1984); Simonson et al. (2014); Snyder and Ives (2003); Talwar and Kacker (1984); Taylor (1980).

2.16 Bioinvasion and Its Impact on Biodiversity

A bionvasive species is defined as a species having been introduced outside its native range through human activities which are likely to cause economic or ecological harm (Chakraborty 2018). Invasion of biological organisms (plants, animals, and microbes) in any ecosystem can be referred to as bioinvasion; invasion of biological organisms to a new ecosystem represents the arrival, settlement, colonization, and establishment of new species into an ecozone away from earlier habitats after traversing at unprecedented rates, routes, and manners (Elton 1958; Williamson 1996; Vitousek et al. 1997).

Alongside several ecological perturbations such as eutrophication, global warming, bio-magnification, biotransformation of persistent pollutants, etc. negative impacts of introduced species having higher bioaccumulation capabilities of invasive species than native species in the on marine estuarine outnumbered the indigenous species by competition them for basic life support resources, and have threatened this ecologically sensitive region considerably by bringing a change in the spesies composition (Chakraborty, 2018).

Introduction of alien and invasive species has been considered as a major threat to the global biodiversity next to habitat destruction (Coblentz 1990; Soule 1990; Gibert et al. 1994). Proper understanding of this phenomenon is still incomplete and inconclusive, although much scientific works on the ecology of invasions have been completed since the subject was first highlighted by Elton (1958).

An invasive species must have the the following attributes:

1. Non-native (alien or exotic) to the affected ecosystem
2. Introduces results of economic or environmental harm
3. Outcompetes and outnumbers the indigenous species
4. Dislodges the habitats and displaces the local native species directly for food, space, or shelter
5. Profusely disrupts the ecodynamics (food chains and food webs) of the affected ecosystems

An alien species that causes harm to the biodiversity, environment, economics, and/or human health is often referred to as invasive alien species.

The trend of destabilizing effects of invasive species has been alarmingly increasing during the last few decades because several reasons such as globalization, free trading, lack of proper ecological knowledge, nonadhering to basic ecological principles in the eco-management of the environment, etc. and the establishment of invasive species in course of time overgrow entire biotic communities and replace the native flora and fauna (Chakraborty 2018).

An invasive species that is not native to a specific location has a tendency to spread very quickly and may cause harm to the environment and also human beings. Invasion success depends upon the preadaptation or on characters which all of the invasive species have evolved after the introduction and settlement in new environment, and this phenomenon has been designated as **a grand experiment in evolution** (Ayala et al. 1989).

2.16.1 Criteria for Designating a Species as Invasive

A harmful invasive species (**Fig. 2.6**) usually displays at least one of the following characteristics in its newly settled aquatic habitat (Chakraborty 2018):

1. Outcompetes, outnumbers, and displaces local native species by competing directly for food, space, or shelter
2. Substantially disrupts the ecodynamics (food chains and food webs) of the affected ecosystems
3. Enjoys prolific reproduction, recruitment, growth, and survival due to "escape" from the natural predators, grazers, parasites, or pathogens that control it in its native range
4. Causes nuisance by fouling to boats, ships, fishing gears, aquaculture equipments, jetties, etc.
5. Renders noxious or pathogenic effects that cause fish mortalities, disrupt aquaculture operations, and/or directly threaten public health, e.g., toxic "red tide" microalgae, waterborne diseases

Besides, the newly introduced species starts enjoying prolific reproduction, recruitment, growth, and survival because of its power of escaping from the natural predators, parasites, or pathogens which are present and control the species in its native range. Several other causes such as nuisance by fouling to boats, ships, fishing gears, aquaculture equipments, jetties, etc. which render a multitude of negative impacts leading to the mass mortalities of fish, disruption of aquaculture activities and impose direct or indirect threats to public health by facilitating the proliferations of the toxic **'red-tide'** microalgae, and pathogens of waterborne diseases (Chakraborty 2018).

2.16.2 Process of Bioinvasion and Prospective Environmental Impacts

Bioinvasion, being a process or phenomenon, takes into account steady but aggressive introduction of invasive species into a new ecozone, new or within the same ecosystem with a different role, and a primarily negative one imposing adverse effects on the ecosystems (Biswas 2003; IUCN 2004).

Understanding the principles of the invasion process will help in predicting the mode of invasion, the pattern of establishment, and intensity of alteration and damage of ecosystems and biodiversity. However, invasion success is related to the biological attributes of the invasive species, the ecological state of the site of invasion, and also an array of stochastic short-term events (Davis et al. 2000; Hobbs and Humphries 1995; Lambrions 2002; Shigesada and Kwasaki 1997). The intensity and magnitude of impacts of invasions although are local, but the drivers of bioinvasion operate in the global context (Chakraborty 2018). At a local scale, the strong impacts of introduced species are wide and different, affecting at different levels, including alteration of ecosystem structure by changing species composition and community structure of invaded areas, thereby affecting ecosystem processes. The intensity and extent of invasiveness depend on the different invasion processes which include transport, introduction, colonization (establishment), and naturalization.

On establishment after settlement in an alien environment, the colonization success depends on many other ecological factors such sediment and water quality parameters, availability of food materials, and also the development of any adversity created by natural, environmental, reproductive, and dispersal barriers. In order to overcome all those constrains and expand territory through population explosion, the invasive species not only get themselves adapted to newly settled habitats but exhibit foraging, reproductive, dispersal, and ecological competence over native organisms.

The International Union for Conservation of Nature (**IUCN)** admits the impacts of **IAS** as "**immense, insidious, and usually irreversible**" and infers that the impacts become much more effervescent in the aquatic ecosystems (**IUCN** 2003). Besides, activities of invasive species after their settlement and colonization cause alteration in the structure and function of an ecosystem, but on the other side, different environmental perturbations such as eutrophication, global warming, salinity invasion, deforestation, soil erosion, etc. attract the invasive species and enable them to successfully settle down in the newly settled habitats and flourish.

In such context, it can be inferred that the bioinvasion mostly concentrate on impacting the ecological, environmental, and economic components. Their mode of impacts has been broadly classified as environmental impacts on natural systems and economic impacts on anthropogenic systems. The range of environmental impacts include three bio-ecological tiers: genetic effects, impacts on biological interactions, and ecosystem effects and the combined effects of which ultimate inhibit the regeneration of native species through competition by exotic species (Perrings et al. 2010).

2.16.3 Aquatic Invasive Species: Aquatic Bioinvasion

2.16.3.1 Global Perspectives

Introduction of species from an alien eco-region began since antiquity and introductions of aquatic organisms to distant localities as a global phenomenon intensified during the last few decades which are for satisfying ever-growing demands in globalized economies towards augmenting aquaculture, controlling vectors, supporting recreational activities, and promoting hobbies such as ornamental fish keeping and gardening. Further, there are unintentional introductions aided through various means of transportation (ballast water of ships). The benefits provided by non-native species to the economy and society notwithstanding a number of species, once established, causes significant and often irreparable damage to the native ecosystems and economies of their new host countries (Chakraborty 2018).

Different aquatic invasive species have been found to exhibit differential ecological and economic threats to several freshwater bodies such as rivers, lakes, and other wetlands throughout the world by displacing the native species and the alteration of hydrologic cycles, affecting nutrient cycles, modifying food web dynamics, introducing diseases and parasites, promoting hybridization with native species, bringing changes in the species composition in fisheries, and the last but not the least designating the exotic species as one of the prime reasons for biodiversity loss.

Aquatic (alien) invasive species (AIS) represents nonindigenous species that threatens the diversity and abundance of native species, alters the ecological stability of aquatic ecosystem, and imposes noxious impacts on agricultural, aquacultural, recreational, and other commercial activities on waters. Aquatic invasive species include nonindigenous species of inland, estuarine, and marine origin, which potentially threaten different trophic interactions, nutrient cycling, and food web dynamics as important ecological processes and cause destruction of natural resources in the aquatic ecosystem (Chakraborty 2018).

The successful invasion process involves three main stages:

1. **Introduction:** the intentional or unintentional introduction of a wild species imported into a region beyond its native range
2. **Establishment:** the establishment and settlement of the species with the scopes or avenues for having required foods and reproductions as self-sustaining reproductive populations
3. **Invasion:** population growth and spreading of the species with **the Global Invasive Species Programme** (**GISP**) as an initiative which seeks to build global cooperation.

2.16.3.2 Aquatic Invasive Species: Indian Perspective

India as a megadiversity country supports the lives of around **8%** of the total number of species recorded worldwide sharing only **2.4%** of the land area of the world but possessing most all the major types of ecosystems of the world (Chakraborty 2003).

The present globalized world with more scopes of international trading has made the movement of peoples all around the world more easier which are supposed to have resulted in the translocation of animals or plants of one biogeographic zone of the world to other regions of the globe. All-round environmental perturbations in different ecosystems of India, especially the coastal ecosystem, have paved the way of not only the introduction of bioinvasive species in those ecologically disturbed ecozones but also enabled them for the successful settlement, colonization, survivability, and propagation which ultimately drive out the indigenous species (Chakraborty 2018).

2.16.3.3 Interaction of Introduced and Resident Species

Proper assessment for the prediction of the direction and magnitude of the mode of actions in disturbing the ecosystem functioning along with affecting the constituent biodiversity components of the ecosystem has appeared to be very difficult. Some novel species with traits very similar to those of the resident species have shown less cascading effects on the ecosystem than other novel species with different traits.

The lack of common evolutionary pressures between an exotic species and a receiving community makes it more likely that the new species will have a novel set of traits that allows it to be a "**supercompetitor**" that influences functioning of the ecosystem. However, an exotic invader after establishing as a superior competitor may fail to become an effective actor for processing and transforming of nutrients and energy.

Experimental studies conducted by Engelhardt and Ritchie (2001, 2002) have shown that the exotic species displaying high growth rate by retaining most nutrients may not be an efficient competitor. Hence ecosystem biomass production and nutrient retention in mixed communities were lower than in the monoculture of the exotic because interspecies competition led to the dominance of a poor biomass producer.

Establishing of **biodiversity–ecosystem functioning (BEF) theory** and interpretating results of relevant experiments on unplanned species colonization have posed five real challenges that must be overcome to have better understanding on the adverse impacts of bioinvasive species on biodiversity in particular and ecosystem functioning in general. These are:

1. Biodiversity acts as both an independent and a dependent variable after the addition of species to the resident community through colonization, and the existing species face the fate of elimination with the passage of time through competitive interactions with the colonizer. Under such context, it is imperative to

understand how **BEF** studies, which typically manipulate diversity as the independent variable and only allow extinction. This can be redesigned to incorporate the inevitable and nonrandom process of new colonizations, in the form of succession or invasion.

2. The establishment of a new species is influenced by biotic factors including the diversity of the resident community along with the competitors and predators. Abiotic factors such as disturbances also influence the new species that in turn affect the resident community. Thus, changes in the diversity within a community after the addition new species cannot be explained only because of the activities of the newly added species, instead of the determining roles of abiotic conditions which bring about the changes in biodiversity and in turn ensure the successful establishment of the species. To develop an understanding on relative impact of biotic and abiotic factors that shape the composition and relevant changes in the biodiversity of the resident species, a long-term monitoring of newly invaded systems is considered as an important prerequisite.
3. Invaders can have a direct impact on ecosystem processes that can nullify the impacts of the resident community on ecosystem processes. However, invaders can also have an indirect impact on ecosystem processes by bringing change in the resident community. These direct and indirect effects of invaders are required to be studied for developing an understanding on the ongoing changes pertaining to the relationship between biodiversity and ecosystem functioning in the communities which are in the process of colonization.
4. Many species that get established in a new location may not be invasive ones but simply blend into the saturating function of the **BEF** relationship. These species tend to display significant latent roles in controlling biodiversity and ecosystem functioning in most of the time but exhibit negative roles on experiencing suitable changes in environmental conditions which are supposed to trigger and facilitate their activities as invasive species.

   Similarly, some species behave as true bioinvasive species as soon as they establish at a new location, but the intensity of their harmful impact decreases with the passage of time. Considerable baseline information are required to assess the intensity and frequency of these latent effects so that right prediction on the consequences of such effects are possible especially in view of global ecological issues such as climate change.
5. Every species possessing near endless number of traits makes it really difficult to assign any novel species as an invasive one without having any knowledge on the traits of all species in a biotic community and also the traits of the colonizer. However, meager consensus can be developed about the functional traits of known invasive species, and even less, if anything, is known about the traits of those yet to come, raising the question of whether the right traits have been measured.

An unrealistic proposition is an attempt to know all traits, and only locating and estimating the plasticity of the key functional traits can become reliable predictors of species' intensity, magnitude, and direction of the impacts imposed by invasive species on both biodiversity and ecosystem functioning. Species can vary broadly in their traits between their native and introduced range (Siemann and Rogers 2001), suggesting that understanding key traits and their plasticity under different abiotic and biotic conditions can play an effective role in identifying and assessing the potential species which tend to pose the greatest risk of changing the **BEF** relationship.

2.16.3.4 Invasion Biology and Ecosystem Services

Bioeconomic theory and modeling incorporate existing research information of the roles of species in shaping biodiversity conservation and ecosystem functioning in order to ensure the quantification of the impact of non-native species on ecosystem services which in turn facilitate the development of effective practices and policy for invasive species management.

It is also imperative to have an understanding of how bioeconomic frameworks have been in use to assess the economic costs and benefits of various actions regarding non-native species and also to incorporate scientific principles pertaining to **biodiversity–ecosystem functioning (BEF)** theory into a strategy for the evaluation of economic impacts of non-native species.

Invasion biology being an offshoot of the subject ecology has emerged as a new emerging branch of science blending with another important branch dealing with biodiversity. **Biodiversity–ecosystem functioning** (**BEF**) is linked through their search for traits that determine the mechanisms by which species pose regulating impact on communities and ecosystems.

It is also needed to know the scope of applicability of the traits to forecast on the prospective influence of novel species after being introduced to a new location on the relationship between biodiversity and ecosystem functioning. The following hypotheses are being proposed with an expectation that all those inferences stimulate further research into the linkages between biodiversity and the different dimensions of ecosystem functioning in open communities (Griffin et al. 2018):

1. Traits that allow species to be good colonizers act as poor predictors of the consequences of species impacts on ecosystem functioning because traits at the juvenile stage are poorly related to traits at the mature stage when impacts on ecosystem processes are most likely to occur. Good colonizers being poor competitors include those species which have limited effects on different biodiversity components in an ecosystem and thereby blend them into the saturating functioning of the biodiversity–ecosystem relationship.
2. Introduced species may not become good dispersers after getting settled in a new location, and thereby such introduced exotic species disobeying the rules of nature impart long-term effects on other biodiversity components of the new habitats. Two types of species with potentially large impacts are:

- **(i)** Those species which directly intervene the ecosystem processes by using a new ecological niche in the changed ecological habitats impose cascading effects on biodiversity
- **(ii)** Those species which establish dominance by gaining a competitive advantage and affecting ecosystem processes through effect traits that differ from resident species.

3. The magnitude and direction of a biodiversity effect on ecosystem functioning differs between open and closed systems. The relationship in closed systems becomes stronger with time and switches from a sampling to a complementary effect, whereas the relationship in open systems is less strong where an invasive species tends to drive community abundance and/or ecosystem processes.

For developing effective methods for the prediction and evaluation of risk of invasion, it is imperative to understand the potential of each species to cause cascading effects on the frameworks of **BEF**. This is thought to be achieved by developing an understanding of similarities and dissimilarities in species traits. In view of doing justice towards preservation of biodiversity within changing environmental issues all over the world, strategies should be adopted keeping in mind inevitable consequence of introduction of novel species by way of present situation of global trade and human travel.

Much of this will rely on understanding of biodiversity and its roles in ecosystem functioning.

2.17 Biodiversity in Tropical Rivers

Tropical Asian rivers are supposed to support a rich biodiversity component which may include a galaxy of benthic invertebrates, good numbers of fishes, and an assemblage of mammals adapted to riverine wetlands.

Widespread sources and supply of allochthonous foods alongside plenty of sunlight trigger growth and proliferation of phytoplankton and other algae which in turn are consumed by zooplankton, benthos, aquatic insects, and herbivorous fishes to be taken up as foods subsequently by carnivorous fishes. Fishes undertake seasonal and annual migrations synchronizing with the changes in meteorological parameters, **viz**., temperature, rainfall, availability of nutrients, etc., for their breeding, feeding, etc. which enable the fishes seasonal occupation of different habitats. Riverine biodiversity is threatened by several causes such as eco-degradation and destruction of habitats (pollution, deforestation of riverine drainage basins), construction of dams and flow regulation, overharvesting, etc.

However, conservation practices in the tropical countries in Asia are constrained by different factors, mostly paucity of baseline of ecological information pertaining to eco-biology of the concerned biodiversity component and the required awareness for undertaking such conservation measures, but the lack of sincere good wishes towards political commitments for the conservation of environmental resources acts as a determinant of the future of riverine biodiversity.

Although tropical Asia located in the oriental biogeographical realm is endowed with a rich flora and fauna in comparison to the neotropical and African counterparts, it is not supposed to invoke the similar serious concern over biodiversity conservation in a comprehensive manner. Asia is the home of charismatic and internationally acclaimed wild fauna such as elephants, several species of primates (orangutan, monkeys, gibbons, langurs, tarsiers, and lorises), both the one horned and two horned rhinos, wild buffalos, gaurs, different species of deers, bears, asses and tigers, lions, species of dog families, and an assortment of smaller cats. Besides, a hoard of amphibia, reptiles, and birds represent the happy residents of tropical rivers and streams (Cubit and Mountfort 1985). Besides, a number of famous rivers of Asia like the Ganges, Indus, Brahmaputra, and Yangtze are not only reservoir of biodiversity but have been recognized worldwide as the cradles of ancient civilizations. Continued and damaging human impacts because of several socio–economic–political factors such as poverty, illiteracy, problems of unemployment, pollution, unplanned urbanization and abrupt land-use changes, political conflicts among neighboring countries, etc. are typical of many Asian rivers and their drainage basins.

It is also very difficult to assess the trend of and extent of eco-degradation of the past and also ongoing human impacts on riverine biodiversity because of non-availability of information of pre-impact conditions.

2.18 Riverine Biodiversity Enrichment: Underlying Ecological Processes

The biodiversity of rivers and streams has been investigated predominantly by the zoologists dealing with diversity and distribution of faunal components as mentioned in the ecological literature (Hynes' 1970; Dudgeon 2000).

However, the roles of producers and decomposers cannot be ignored; instead they are being considered as the main actors of the trophic interactions. In pelagic or limnetic areas of lotic systems, cycling of organic substances is mainly driven by planktonic food web where phytoplankton constituting the primary trophic level are used by herbivorous zooplankton or smaller fishes as foods and thereby trigger the cycling of matters in open water systems.

By contrast, the linkage between heterotrophic bacteria, protists, and larger detritivores forms the unique **microbial loop**, and though these foods and feeding relationships constitute another important pathway for matter cycling in pelagic food webs (Azam et al. 1983). Dissolved organic matter **(DOM)** after being released by phytoplankton as intermediate products of photosynthesis and/or as autolytic products (Riemann and Søndergaard 1986) is utilized for the growth of heterotrophic bacteria, followed by grazing of bacteria by protistan which thereafter are consumed by meso-zooplankton such as cladocerans and/or copepods.

Simultaneously, aggregation of **DOM** under some chemical processes produces abiotic particles (particulate organic matters) with sizes of some of which are similar to those of planktonic bacteria, containing **DNA**, lipids, sugars, and proteins which act as important food items for bacteria grazers such as Protista (Kerner et al. 2003). The structure and function of lotic water ecosystem are therefore based on the relationships and continuous interactions starting from dissolved organic matters, particulate organic matters, phytoplankton, zooplankton, fishes, to other higher consumers.

The initial substructuring recognizes the origin of organic substance from within (autochthonous) or outside the system (allochthonous). The second level of partitioning indicates the fundamental biochemical difference between producers and consumers. The third-order compartmentalization is based on turnover or replacement times of the lotic organisms, which is related to size.

A final pattern reflects differences in the structure and function of organisms in relation to physical differences in running water habitats such as organisms in the water column which are plankton and nekton while those associated with the sediments, either motile or sessile, are benthos.

2.19 Habitat Heterogeneity and Distribution of Lotic Animals

The lotic animals tend to adapt in three habitat types, erosional, intermediate, and depositional, which are considered primarily as energetic, with problems of concealment from predators and competition. Such adaptabilities in turn enable the lotic faunal components to exploit various microhabitats, which comprise the matrix of each of the broad categories, primarily concerned with the function of the majority of the animals (feeding and growth) and, to a lesser extent, reproduction. The majority of the aquatic insects which lead a life in the aquatic environment as periphyton (attached with hard/solid structures) or as benthos in ecologically healthy streams and rivers meet their reproductive needs utilizing the resource bases in the adjoining terrestrial environment.

Energy budgeting appears to be another important adaptive prerequisite as, out of all metabolic and biological processes, respiration represents the most costly portion involving maximum energy expenditure patterns, followed by growth and reproduction. Since highest respiration costs are closely linked to locomotion, animals associated with maximum respiration cost are being contemplated as competitor of the growth, and in such context the general adaptive strategy is to minimize locomotion and thereby reducing the amount of energy to be spent for movement and maximize feeding, thereby maximizing growth (Coffman et al. 1971, Cummins, and Wuycheck, 1971).

Nektons in lotic system are defined as the animal forms mostly inhabiting mostly the water column which can change their position independent of water movements, that is, capable of significant locomotion on their own (Hutchinson 1967). However, most of the animals are capable of significant locomotion, especially benthic forms in the drift.

The term nekton has therefore been employed to cover all animals in the water flowing over the substrate. Another important pelagic faunal component in the riverine ecosystem is plankton which is defined as drifting organisms without any locomotory abilities and is dependent for their locational change either horizontally or vertically.

Obviously, the nekton is much less restricted to the erosional depositional ecozones than is the benthos. However, some fishes, a major representative of nekton, often feed, hide, and spawn in different regions of sedimentary bottoms of the water bodies.

2.19.1 Erosional Zone Biotic Assemblages

Most of the benthos are encountered in the riverine drift, with the erosional areas which represent the primary region of origin. Therefore, the drift and the benthos are primarily dominated by several mollusks, insects, annelids, and crustaceans and in the "microdrift" protozoans and rotifers. Streamlined shape of the fishes is considered as an important adaptive manifestation of this nekton inhabiting fast-running waters, primarily species feeding in or just below the erosional areas.

Actually, the fish used to use erosional lotic habitats mostly for their breedings and spend a large proportion of their time in micro-depositional areas, for example, behind large boulders, underwater trunks of aquatic plants, or other hard structures. More diversities of fishes were encountered in larger rivers where the flow is rapid over coarse substrates. The erosional benthic assemblages of running waters constitute only strictly lotic benthic fauna. The adaptations of the benthos of fast-flowing areas have become possible by developing in those animals permanent and temporary structures for attachment to the substrate and dorsoventral flattened bodies for the easy movements through the water.

A ring of hooks allows the filter-feeding simuliid dipteran larvae to remain firmly attached to smooth surfaces overridden by laminar flow, even in torrential currents. The actual attachment and movement is over a mat of silk spun from the salivary glands and laid down by the larvae over the substrate. Hooks on the posterior proleg hold the larva in place while it feeds by entrapping small particles in a pair of expandable, fanlike structures on the head. Movement along the substrate is accomplished by alternate attachment of the ventral anterior and posterior prolegs. Owing to the presence of true in leeches and also in the curious dipteran family such as Blephariceridae and both of these animals can sustain the rapidly flowing waters of their habitats and are very seldom observed on the exposed upper surfaces of sediments. The foot–shell structure of gastropods and the adhesion pad of *Hydra* species inhabiting erosional areas provide sucker-like attachment devices (Dudgeon 2000).

2.19.2 Intermediate Zone Biotic Assemblages

The benthos of intermediate areas accommodates representatives from both erosional and depositional habitats; however, some faunal components exhibit maximum abundance in sand–gravel-dominated riverine tracts having moderate to low flow.

The ephemeran mayflies and a number of species under the genus of *Pycnopsyche*, of caddisflies with the lighter mineral-cased caddis larvae by virtue of their gravel-burrowing adaptation can inhabit this zone.. Dominant predators of intermediate assemblages are species of *Sialis* (Megaloptera) and *Atherix variegata* (Diptera, Rhagionidae), which feed on the diamesin midge fauna of these areas.

The faunal elements of both erosional and depositional nektons are found in intermediate transitional areas of moderate flow over sand–gravel substrates. The faunal diversity of the larger rivers is greatly simplified because of their highly degenerate state resulting from decades of gross pollution. Hynes (1970) has documented that the smaller stony streams, being the representative of lotic habitat, have a truly distinctive fauna throughout the world.

The surface and interstitial benthic organisms are usually dominated, both in respect of their abundance and biomass, mostly by the insects, although in some large rivers, high abundances of gastropods, bivalves, crustaceans, etc. are encountered. Also, in pollution-altered, running waters, annelids are often the dominant forms, tubificids sometimes reaching amazing numerical densities.

Perhaps the most common adaptation among the rapid water invertebrates is dorsoventral flattening. Compressed body form allows the animal to avoid the major thrust of the current by moving through crevices among the coarse sediment particles constituting the erosional habitats and along the boundary layer at the water–sediment interface.

Small size, enhanced by dorsoventral flattening, allows many species to move over the sediments below high velocity currents. Some faunal components such as leptophlebeid mayflies, perlid stoneflies, and fast-water-dwelling flatworms (Dugesis and Phagocata) move primarily in the boundary layer, a layer of about few mm thickness above the surface of the substrate with reduced flow.

A number of fishes leading benthic life in erosional habitats increased the drift in their immediate vicinity at the time of their feeding. However, the increased general flow in rapidly running sections results in a microfauna associated with a predominantly aerobic sedimentary system which differs from that of the anaerobic sediments that often characterizes depositional areas and occasionally develops in intermediate zones (Hynes 1970).

2.19.3 Depositional Zone Biotic Assemblages

As regions of slack water in the rivers or streams, characterized by the deposition of finer sediment particles, are often indistinguishable from truly lentic habitats of the same region. The same genera, and often the same species, of protozoans, rotifers, and microcrustaceans (amphipods, copepods, small shrimps) as those encountered in lentic water bodies are seen to inhabit the slow-water areas, especially within large rivers.

All of these organisms are characterized in having weak swimming capabilities coupled with high reproductive rates and short generation times, capable of replacing any displacement from depositional regions to erosional zones further along the watercourse. Algae constitute the food base for engulfing sarcodin protozoans and filter-feeding organisms such as ciliates, monogonont rotifers, copepods, and cladocerans and thereby influence the settlements of those faunal components.

However, higher activities of detritivores are encountered in lotic systems with higher availability of particulars organic matter than do standing waters. Although annelids, nematodes, and midges in the tribe Chironomini are encountered among both the erosional and intermediate assemblages, they are much more typical of depositional zones, where they burrow into the upper layers of the sediments.

These fine sediments represent not only the inhabited matrix but also the food supply for such organisms. The high organic content of such substrate attracts microconsumers (decomposers and microfauna) similar, if not identical, to those typical of organic accumulations in the fast and intermediate flow sections.

The lumbriculid annelids are more encountered as very common faunal components in erosional and intermediate zones, whereas the species belonging to the families Naididae and Tubificidae are found mostly in fine sediments. Among the more interesting burrowing forms, the flattened predaceous gomphid dragonfly nymphs, living with only the eyes and tip of the abdomen exposed, are found. Burrowing mayflies (especially *Hexagenia*) which maintain broad **U**-shaped tubes in the fine sediments are common in large rivers and frequently represented in small streams. The thinner shelled pelecypods (*Anodonta*) are found to be well adapted in depositional habitats, particularly in large rivers by extending their incurrent and excurrent siphons above the water–sediment interface.

The damselfly *Calopteryx* is extremely common in depositional habitats formed along stream margins, where it preys upon midges, amphipods, and other silt-dwelling forms. The predaceous hemipterans *Belostoma*, *Ranatra*, and *Lethocerus* usually inhabit the same areas as *Calopteryx*, undoubtedly with some overlap in food habits. Detrital and animal-feeding stoneflies, such as *Taeniopteryx*, are often abundant in cold, small streams. Watercress beds are developed where small springs enter streams, which appear to be depositional, even though the watercress beds exist as islands in generally erosional or intermediate sections. Mostly these watercress beds are inhabited by amphipods. As in the lentic environment, lotic plant beds abound with climbing damselflies (*Ischnura* and *Agrion*), dragonflies (*Anax* and *Libellula*), and organic case-bearing caddisflies (species under the families of Phryganeidae, Leptoceridae, and Limnephilidae) (Hynes 1970).

The fish, represented mainly by cyprinids (minnows), centrarchids (sunfishes), ameiurids (bullheads), and catostomids (suckers), prefer to inhabit depositional sections which are characterized in having laterally compressed, less rounded, and streamlined body form. Those fish depend mostly for their foods on slow-water benthos, organic detritus, and some "**planktonic**" forms, supplemented by terrestrial invertebrates. The settlement, growth, and expansion of vascular hydrophytes in depositional areas further transform this habitat as to be very similar to that of shallow lentic water bodies. In addition, these not only support the lives of a sizeable portion of periphyton but also facilitate the sedimentation by reducing the current of water and also generating **DOM** through the decomposition of their biomass (Hynes 1970).

2.20 Ecological Relationships of Faunal Components with Running Water

Trophic relationships, food gathering, and therefore the morphological–behavioral adaptations that form its basis are considered the paramount animal consumer functions in lotic ecosystem which include the general strategy of animals to restrict energy-costing locomotion in favor of feeding. In a detailed study of the trophic relations of the benthos (including sculpins) of a stream (Cummins, 1964; Cummins et al. 1964; Coffman et al. 1971), several basic features became apparent. Most organisms were predominantly herbivore, detritivore, or carnivore. Food habits are more closely related to size than to species; for example, the early instars of most insect species, even those destined to be predators later in their growth cycle, were detritivores, feeding on particulate and amorphous organic material and the associated microbial assemblages. As this indicates, the early stages of the majority of the insects are associated with organic accumulation in macro-depositional zones (the margins of the running watercourse, backwaters, pools, etc.,) or in micro-depositional pockets (the interstices of the sediments or **shadows** behind large substrate units), which thus serve as the **nurseries** for many of the benthic species.

Herbivory is more common in the central channel portions of erosional and intermediate sections, where the dominant food source is represented by epilithic diatoms and certain filamentous green algae. In depositional areas, where more blue-green algae are found, the vascular hydrophytes constitute a food base for herbivores, primarily leaf-mining dipterans and lepidopterans and a few leaf-eating caddisflies, such as certain species under the families of Phryganeidae, Leptoceridae, and Limnephilidae.

The vascular plant tissues which are not preferred as food items are seldom eaten by the aquatic fauna and more often enter the food cycle as detritus. The primary interaction between the nekton and the benthos, other than the resettling of drift organisms in new areas, is through feeding: removal of fine particles from the water by benthic animals through a variety of filtering devices and predation by nektonic fishes on benthic species.

The benthic system has many more self-contained predator prey cycles than does the nekton system. The only predation by benthic species on nektonic organisms is on animals in the drift of benthic origin. Some predaceous benthic species are found to become detritivores in their early phases of life cycle, and many large detritivore–herbivores ingest small animals as they reach the end of their growth cycle. Similarly, the gut contents of most benthic predators contain small amounts of detritus and algae, as foods with nutritional significance which often swept into the mouth during capture of the prey (Hynes 1970).

2.20.1 Eco-complementation: Mutualistic Relationship Between Natural Process and Biodiversity Development

Out of so many ecological parameters operating independently or in combination in limiting the distribution and abundance of biotic components of river ecosystem, temperature is considered as the most vital parameter in regulating the growth and reproduction as of most of the river fauna which are ectotherms. The faunal components of the upstream with comparatively cold clines in the mountain or hilly zones having higher altitudes cannot thrive in the downstream, mostly within the plains experiencing higher temperature and vice versa. Besides, species inhabiting a specific thermal regime of one river can also survive and flourish in very similar ecological setup of other rivers, getting all other life-supporting ingredients (nutrients, substratum, and water with preferred abiotic factors) within the biogeographical range of that species. Therefore, most of the invertebrates (insects, mollusks, crustacea) and fish are seen in those areas of streams and rivers which fulfill their thermal requirements where the needs of substratum, food, and other resources remain marginal.

Such things are supposed to have been resulted mainly because of the species-specific thermal energetics of growth which involves many life history stages ensures, emergence of different instars in insects by ecdysis and facilitate spawning of fishes which are initiated and regulated by precise temperature cues. Additionally, food limitations have been found to be less prevalent than thermal limitation most of the time.in some riverine organisms having highly specialized food requirements. This is exemplified by the production and supply of allochthonous coarse particulate organic matter derived from the decomposition of leaves and grasses of headwater streams shaded by riparian plants, the distribution of which is limited by availability of light and nutrients in one hand and which drives instream bioproduction on the other (Cummins **et** al., 1984, 1989).

Besides, dissolution of the bedrock and other geological formation through varied forms of geochemical reactions, generates and supplies nutrients and other dissolved solids to the main flows of rivers and streams. The streams displaying high alkalinity in the water due to the continuous dissolution from limestone lead to develop more productive aquatic ecosystem in comparison to those streams draining more inert bedrocks, such as granite massifs (Kruger and Waters 1983; Waters et al., 1990). The growth and biomass formation of algae and other macrophytes of riverine ecosystem are driven by such dissolved solids into spiral downstream, alternatively retained and released into transport by the river food-webs (Newbold et al. 1981, 1982). However, in return effects, heterotrophy coupled with turbidity of water are resulted in the slow moving reaches near the river mouth because of the effects of planktonic microbial decomposition of organic matter transported from upstream reaches, and tended to inhibit the penetration of light which are to the bottom of rivers (Vannote and Sweeney 1980a; Minshall et al. 1983; Naiman et al. 1987).

2.21 Biotic Interactions: In Biological Processes of Streams

Intricate interactions among different biotic components through several bio-ecological processes influence the structure and function of stream ecosystems, including habitat selection, feeding, competition, and predation. These processes are not completely independent of each other as access to food and avoidance of predators are being considered as prime determining force for habitat selection, of any species which in turn impel habitat selection by other species. The collective behaviors of several species and many individuals interact to structure biological communities, including the spatial arrangement of species and configuration of food webs.

These biological processes are particularly important for aquatic animal with the power of mobility such as insects, crustaceans, and fishes, which cannot control their movement and choice of habitats. Because migration and habitat selection allow species to move to suitable habitats, areas of high habitat diversity vis-à-vis habitat heterogeneity such as boulder headwater streams, island-braided reaches, or tributary confluences tend to have high species diversity as those habitats are preferred by biotic diversity (Jackson et al. 2001; Kiffney et al. 2003; Rice et al. 2006; Gooderham et al. 2007).

Fishes, crustaceans, and invertebrates select habitats for a variety of needs including access to food resources, refuge from strong currents or predators, or reproduction. Stream fishes feeding on drifting invertebrates usually occupy an area that provides cover from predators and relief from current (behind and under large wood or boulders) while at the same time offering a good view of food moving towards them in the water (Hughes 1995).

Similarly, many invertebrates require particular flow conditions to optimize food delivery in the water column, and rivers with high habitat diversity offer the largest range of functional flow conditions for invertebrates (Wetmore et al. 1990; Hart and Finelli 1999). In addition to habitat selection for resting and feeding requirements, many aquatic organisms also adjust their habitat selection to avoid predation.

For instance, some aquatic insects such as black fly larvae (family Simuliidae) find a refuge from predation by flatworms (phylum Platyhelminthes) and other predators by selecting fast currents where their predators are unable to pursue them (Hart and Merz 1998). Fishes (especially small ones) often use complex hiding cover such as roots, wood jams, or aquatic macrophytes to avoid predators.

By contrast, species such as crayfish move to shallow water as juveniles to avoid predation by fishes, but, as they grow larger (and are too large for fish to eat them), these crayfish move to deeper water to avoid predation by birds and mammals (Englund and Krupa 2008). Even the egg-laying behavior of many aquatic insects depends on having appropriate flow conditions and bed morphology with rocks protruding from the surface to allow adults to crawl under them (Lancaster et al. 2010).

These same types of habitat requirements influence the distribution and the abundance of many stream organisms that require particular arrangements of physical habitats to secure food and find refuge from predators. These instream biological processes vary with riparian conditions, stream flow, and habitat diversity, each of which can alter the availability of habitats and food resources and thereby alter food webs and community structure. For example, food webs in streams are based on two key basal resources: materials that enter from the riparian area (leaf litter, terrestrial invertebrates, and seeds) and primary production within streams (algae, mosses, rooted aquatic plants) (Richardson et al. 2010). In streams with high inputs of leaf litter, invertebrate communities occupying the base of the food web may exhibit ability to freely exploit shifting habitats as shown by shredders and collectors that feed on detritus.

In contrast, invertebrate communities within streams with lower leaf litter inputs and higher availability of light may be dominated by grazers or scrapers that are adapted to feeding on benthic algae. In either of these environments, changes in amounts of litter or light reaching the stream have significant effects on stream processes. Seasonal flow conditions and habitat heterogeneity also influence biological processes that affect population dynamics of stream organisms. Flow disturbance such as flooding causes changes in habitats, reductions in basal resources, and direct mortality of organisms, providing habitat opportunities for organisms with rapid life cycles and good colonizing ability (Wootton et al. 1996).

Low-flow periods have been found to result in mortality of species incapable of responding on the appropriate time scales, thereby succumbing to desiccation (McAuliffe 1984). Similarly, increases in fine sediment supply can shift invertebrate taxa toward burrowing species, which reduces food supply and growth rates for juvenile salmonids (Suttle et al. 2004).

2.22 Riverine Biodiversity of South West Bengal (Tables 2.1, 2.2, 2.3, 2.4, 2.5, 2.6, 2.7, 2.8, 2.9, 2.10, 2.11, 2.12, 2.13, 2.14, and 2.15)

A biotic community representing a unit of biotic assemblages of plants, animals, or both in a unit area experiencing biotic interactions within riverine habitat render significant contribution for the sustenance of the entire riverine ecosystem ecological significance. Different parts of the river ecosystem are affected differently by anthropogenic activities especially by releasing untreated domestic sewage and industrial effluents, agrochemicals, etc. which influence considerably the community interaction processes. Rooted macrophytes absorb chemicals from both soil and water by penetrating with their roots deep into the bottom, but soil dependent burrowing faunal components contribute for resuffling of the textural components of the sediments along side ensuring the nutrients availability to drive the functioning of the entire ecosystem. The main column of the water bodies is inhabited by most of the fish, plankton, many macrophyte shoots, other invertebrates, diatoms, etc. on which large algae, aquatic birds, aquatic insects, reptiles, and mammals depend for food.

The surface of water is mostly covered by the occurrence of floating macrophytes, microphytes, various invertebrates such as water skaters, other aquatic insects, and birds. Above the water surface of the river ecosystem and within the littoral (shallow water) zones, a unique assemblage of plants comprising herbs, shrubs, grasses, and trees along with their faunal associates-both invertebrate, amphibians, reptiles, birds and mammals which spend part of their life cycle in the river as resting places, burrows and homes of the frogs, snakes, water monitor, lizards, tortoises and turtles, crocodiles, Passeriformes (mayna, crows, beeaters, barbets, robins, etc.) and aqaytic birds (egretes, herones, kingfishers, otters, ducks, teals, swan, etc.) and other mammals.

2.22.1 Macrophytes: Ecology and Functional Roles

Diversity, distribution, and functional roles of water being the chief constituent and the medium of life on earth support the lives of a diversity of macrophytes and larger aquatic plants in the riverine system which provide habitat, shelter, and indeed food for many animals and smaller plants. The natural riverine flows of water maintain a natural balance of plants and animals, some of which are interdependent, or competing, or independent in nature.

Table 2.1 List of plant species recorded in different ecozones in and around six rivers of South West Bengal, India

Sl. No.	Family and species	Dwarkeswar			Silabati			Rupnarayan			Kansai			Keleghai		Subarnarekha			
		PrM	M	PoM	PrM	M	PoM	PrM	M	PoM	PrM	M	PoM	PrM	M	PoM	PrM	M	PoM
	Terrestrial																		
	Amaranthaceae																		
1	*Aerva aspera*	–	+	–	–	+	–	–	–	–	–	+	–	–	–	–	–	+	–
2	*Amaranthus spinosus*	–	+	–	–	+	–	–	–	–	–	+	–	–	–	–	–	+	–
3	*Celosia argentea*	–	+	–	–	+	–	–	–	–	–	+	–	–	+	–	–	+	–
4	*Gomphrena decumbens*	–	+	+	–	+	+	–	–	–	–	+	+	–	+	+	–	+	+
	Asteraceae																		
5	*Eupatorium odoratum*	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	+
6	*Grangea maderaspatana*	–	–	+	–	–	+	–	–	+	–	–	+	–	–	+	–	–	+
7	*Mikania scandens*	–	–	+	–	–	+	–	–	+	–	–	+	–	–	+	–	–	+
8	*Parthenium hysterophorus*	–	–	+	–	–	+	–	–	+	–	–	+	–	–	+	–	–	+
9	*Tridax procumbens*	–	–	+	–	–	+	–	–	+	–	–	+	–	–	–	–	–	+
10	*Vernonia cinerea*	–	+	–	–	+	–	–	+	–	–	+	–	–	–	–	–	+	–
	Boraginaceae																		
11	*Heliotropium curassavicum*	–	+	+	–	+	+	–	+	+	–	+	+	–	+	+	–	+	+
12	*Heliotropium indicum*	–	+	+	–	+	+	–	–	–	–	+	+	–	+	+	–	+	+
13	*Heliotropium supinum*	–	+	+	–	+	+	–	+	+	–	+	+	–	+	+	–	+	+
	Brassicaceae																		
14	*Nasturtium indicum*	–	+	–	–	–	–	–	–	–	–	–	–	–	+	–	–	+	–
	Capparidaceae																		
15	*Cleome viscosa*	–	+	–	–	+	–	–	–	–	–	+	–	–	+	–	–	+	–
	Chenopodiaceae																		
16	*Chenopodium ambrosioides*	–	+	–	–	+	–	–	–	–	–	+	–	–	–	–	–	+	–

(continued)

Table 2.1 (continued)

Sl. No.	Family and species	Dwarkeswar			Silabati			Rupnarayan			Kansai			Keleghai		Subarnarekha			
		PrM	M	PoM	PrM	M	PoM	PrM	M	PoM	PrM	M	PoM	PrM	M	PoM	PrM	M	PoM
	Convolvulaceae																		
17	*Evolvulus nummularius*	–	+	–	–	+	–	–	+	–	–	+	–	–	+	–	–	+	–
	Euphorbiaceae																		
18	*Acalypha indica*	+	+	–	+	+	–	–	–	–	+	+	–	–	–	–	+	+	–
19	*Croton bonplandianum*	–	+	–	–	+	–	–	–	–	–	+	–	–	+	–	–	+	–
20	*Euphorbia hirta*	–	+	+	–	+	+	–	+	+	–	+	+	–	+	+	–	+	+
21	*Euphorbia microphylla*	–	–	–	–	+	+	–	–	–	–	+	+	–	+	+	–	–	–
22	*Phyllanthus simplex*	–	+	–	–	+	–	–	–	–	+	+	–	–	–	–	+	+	–
23	*Phyla nodiflora*	–	+	–	–	+	–	–	–	–	+	+	–	–	–	–	+	+	–
24	*Jatropha curcas*	–	–	–	–	+	–	–	+	–	–	+	–	–	–	–	+	+	–
25	*Jatropha gossypifolia*	–	+	–	–	+	–	–	+	–	–	+	–	–	+	–	+	+	–
	Fabaceae																		
26	*Alysicarpus monilifer*	–	+	–	–	+	–	–	–	–	–	+	–	–	+	–	–	+	–
27	*Mimosa pudica*	+	+	–	+	+	–	+	+	–	+	+	–	+	+	–	+	+	–
28	*Phaseolus trilobus*	+	+	–	+	+	–	–	–	–	+	+	–	–	–	–	+	+	–
	Lamiaceae																		
29	*Leucas aspera*	–	+	–	–	+	–	–	–	–	–	+	–	–	+	–	–	+	–
	Malvaceae																		
30	*Sida cordifolia*	–	–	+	–	–	+	–	–	–	–	–	+	–	–	+	–	–	+
	Meliaceae																		
31	*Azadirachta indica*	–	–	+	–	–	+	–	–	–	–	–	+	–	–	+	–	–	+
	Myrtaceae																		
32	*Barringtonia acutangula*	–	+	–	–	+	–	–	–	–	–	+	–	–	+	–	–	+	–
	Passifloraceae																		

33	*Passiflora foetida*	–	+	+	–	+	+	–	–	–	–	+	+	–	+	+	–	+	+
	Poaceae																		
34	*Digitaria sanguinalis*	–	+	–	–	+	–	–	–	–	–	+	–	–	+	–	–	+	–
35	*Eragrostis cynosuroides*	–	+	–	–	+	–	–	–	–	–	+	–	–	+	–	–	+	–
36	*Imperata cylindrica*	–	+	–	–	+	–	–	–	–	–	+	–	–	+	–	–	+	–
37	*Oryza sativa*	–	+	–	–	+	–	–	–	–	–	+	–	–	+	–	–	+	–
38	*Panicum flavescens*	–	+	–	–	+	–	–	+	–	–	+	–	–	+	–	–	+	–
39	*Paspalidium sorobiculatum*	–	+	–	–	+	–	–	–	–	–	+	–	–	+	–	–	+	–
40	*Saccharum officinarum*	–	+	–	–	+	–	–	–	–	–	+	–	–	+	–	–	+	–
	Polygonaceae																		
41	*Polygonum plebeium*	–	+	–	–	+	–	–	+	–	–	+	–	–	–	–	–	+	–
	Portulacaceae																		
42	*Trianthemum portulacastrum*	–	+	–	–	+	–	–	–	–	–	+	–	–	+	–	–	+	–
	Rubiaceae																		
43	*Oldenlandia corymbosa*	–	+	–	–	+	–	–	+	–	–	+	–	–	+	–	–	+	–
44	*Oldenlandia biflora*	–	+	–	–	+	–	–	+	–	–	+	–	–	+	–	–	+	–
	Sapindaceae																		
45	*Cardiospermum halicacabum*	–	+	–	–	+	–	–	+	–	–	+	–	–	+	–	–	+	–
	Scrophulariaceae																		
46	*Scoparia dulcis*	–	+	–	–	+	–	–	–	–	–	+	–	–	–	–	–	+	–
	Solanaceae																		
47	*Physalis minima*	–	+	+	–	+	+	–	–	–	–	+	+	–	+	+	–	–	–
48	*Solanum torvum*	–	+	+	–	+	+	–	+	+	–	+	+	–	+	+	–	+	+
49	*Solanum xanthocarpum*	–	+	+	–	+	+	–	+	+	–	+	+	–	+	+	–	+	+
	Sterculiaceae																		
50	*Pentapetes phoenicea*	–	+	–	–	–	–	–	–	–	–	+	–	–	–	–	–	+	

(continued)

Table 2.1 (continued)

Sl. No.	Family and species	Dwarkeswar			Silabati			Rupnarayan			Kansai			Keleghai		Subarnarekha			
		PrM	M	PoM	PrM	M	PoM	PrM	M	PoM	PrM	M	PoM	PrM	M	PoM	PrM	M	PoM
51	*Guazuma tomentosa*	–	–	–	+	+	–	+	+	–	–	–	–	–	–	–	+	+	–
	Tiliaceae																		
52	*Corchorus acutangulus*	–	+	–	–	–	–	–	–	–	–	+	–	–	+	–	–	+	–
	Verbenaceae																		
53	*Lippia alba*	–	+	+	–	+	+	–	–	–	–	+	+	–	–	–	–	+	+
54	*Lippia geminata*	–	+	+	–	+	+	–	–	–	–	+	+	–	–	–	–	–	–
	Violaceae																		
55	*Ionidium suffruticosum*	–	+	–	–	+	–	–	–	–	–	+	–	–	–	–	–	+	–
	Aquatic																		
	Amaranthaceae																		
56	*Tilanthera philexoroides*	+	+	–	+	+	–	–	+	+	–	+	+	–	–	–	+	+	–
	Apiaceae																		
57	*Hydrocotyle asiatica*	–	+	–	–	+	–	–	–	–	–	+	–	–	–	–	–	+	–
	Convolvulaceae																		
58	*Ipomoea aquatica*	–	+	–	–	–	–	–	–	–	–	+	–	–	+	–	–	+	–
59	*Ipomoea carnea*	–	+	–	–	+	–	–	+	–	–	+	–	–	+	–	–	+	–
	Fabaceae																		
60	*Aeschynomene aspera*	–	+	+	–	–	–	–	–	–	+	+	–	–	–	–	–	–	–
	Hydrocharitaceae																		
61	*Hydrilla spiralis*	–	+	–	–	+	–	–	–	–	–	+	–	–	+	–	–	+	–
	Onagraceae																		
62	*Jussiaea repens*	–	+	–	–	+	–	–	+	–	–	+	–	–	+	–	–	+	–
63	*Ludwigia parviflora*	–	+	+	–	+	+	–	+	+	–	+	+	–	–	–	–	+	+
	Polygonaceae																		

64	*Polygonum hydropiper*	−	+	−	−	+	−	−	+	−	−	+	−	−	+	−	−	+	−
65	*Polygonum orientale*	−	+	−	−	+	−	−	−	−	−	+	−	−	+	−	−	+	−
	Pontederiaceae																		
66	*Eichhornia crassipes*	−	+	+	−	+	+	−	−	−	−	+	+	−	+	+	−	+	+
	Semiaquatic																		
	Acanthaceae																		
67	*Hygrophila polysperma*	−	+	−	−	+	−	−	−	−	−	+	−	−	+	−	−	+	−
	Aizoaceae																		
68	*Mollugo spergula*	−	+	−	−	+	−	−	+	−	−	+	−	−	−	−	−	+	−
	Amaranthaceae																		
69	*Alternanthera paronychioides*	−	+	−	−	+	−	−	−	−	−	+	−	−	+	−	−	+	−
70	*Alternanthera sessilis*	−	+	−	−	+	−	−	+	−	−	+	−	−	+	−	−	+	−
71	*Alternanthera tenella*	−	+	−	−	+	−	−	+	−	−	+	−	−	+	−	−	+	−
	Asteraceae																		
72	*Xanthium strumarium*	−	−	+	−	−	+	−	−	+	−	−	+	−	−	+	−	−	+
73	*Eclipta alba*	−	−	+	−	−	+	−	−	−	−	−	+	−	−	+	−	−	+
	Chenopodiaceae																		
74	*Chenopodium album*	−	+	−	−	+	−	−	−	−	−	+	−	−	−	−	−	+	−
75	*Trianthema portulacastrum*	−	+	−	−	+	−	−	−	−	−	+	−	−	+	−	−	+	−
	Commelinaceae																		
76	*Commelina benghalensis*	−	+	−	−	+	−	−	+	−	−	+	−	−	+	−	−	+	−
	Convolvulaceae																		
77	*Merremia emarginata*	−	+	−	−	+	−	−	+	−	−	+	−	−	+	−	−	+	−
	Cyperaceae																		
78	*Cyperus rotundus*	−	+	−	−	+	−	−	+	−	−	+	−	−	+	−	−	+	−
	Marsileaceae																		
79	*Marsilea quadrifolia*	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+

(continued)

Table 2.1 (continued)

Sl. No.	Family and species	Dwarkeswar			Silabati			Rupnarayan			Kansai			Keleghai		Subarnarekha			
		PrM	M	PoM	PrM	M	PoM	PrM	M	PoM	PrM	M	PoM	PrM	M	PoM	PrM	M	PoM
	Portulacaceae																		
80	*Portulaca oleracea*	–	–	–	–	+	–	–	+	–	–	+	–	–	–	–	–	+	–
	Rubiaceae																		
81	*Dentella repens*	–	–	+	–	–	+	–	–	+	–	–	+	–	–	+	–	–	+
	Scrophulariaceae																		
82	*Bacopa monnieri*	–	+	–	–	+	–	–	–	–	–	+	–	–	–	–	–	+	–
83	*Vandellia crustacea*	–	+	–	–	+	–	–	+	–	–	+	–	–	+	–	–	+	–
	Sterculiaceae																		
84	*Melochia corchorifolia*	–	+	–	–	+	–	–	–	–	–	+	–	–	+	–	–	+	–

M = monsoon; PoM = postmonsoon and PrM = pre-monsoon

Table 2.2 Similarity index in respect of all species of vegetation (result expressed in %)

	Dwarkeswar	Shilabati	Rupnarayan	Kansai	Keleghai	Subarnarekha
Dwarkeswar		94.3	57.4	99.4	83.2	95.6
Shilabati			63.1	97.5	80.9	94.9
Rupnarayan				60.3	57.4	62.0
Kansai					82.6	97.5
Keleghai						82.6
Subarnarekha						

Table 2.3 Similarity index in respect of all of species of terrestrial plants (result expressed in %)

	Dwarkeswar	Shilabati	Rupnarayan	Kansai	Keleghai	Subarnarekha
Dwarkeswar		94.1	50.7	100.0	81.8	95.1
Shilabati			56.3	98.0	79.5	93.2
Rupnarayan				53.5	52.6	55.6
Kansai					81.6	97.1
Keleghai						80.9
Subarnarekha						

Table 2.4 Similarity index in respect of all species of aquatic plants (result expressed in %)

	Dwarkeswar	Shilabati	Rupnarayan	Kansai	Keleghai	Subarnarekha
Dwarkeswar		90.0	62.5	100.0	77.8	95.2
Shilabati			71.4	90.0	75.0	94.7
Rupnarayan				62.5	50.0	66.7
Kansai					77.8	95.3
Keleghai						82.3
Subarnarekha						

Table 2.5 Similarity index in respect of semiaquatic plants (result expressed in %)

	Dwarkeswar	Shilabati	Rupnarayan	Kansai	Keleghai	Subarnarekha
Dwarkeswar		97.1	71.4	97.1	90.3	97.1
Shilabati			61.1	100.0	87.5	100.0
Rupnarayan				75.9	72.0	75.9
Kansai					87.5	100.0
Keleghai						87.5
Subarnarekha						

2.22.1.1 River–Macrophyte Interactions

Riparian systems representing a transitional ecozone in between water bodies and surrounding elevated land mass developing a landscape within which the biotic components representing the aquatic and terrestrial habitats interact (Naiman et al. 2005). Riparian zones are also considered as very complex ecotone having its unique

Table 2.6 Characteristic features and habitats of major groups of freshwater algae

Group (common name)	Dominant pigments	Cell wall	Habitats	Approximate of species (% freshwater)	Ecological importance
Cyanobacteria	Chl a, phycobilins	Peptidoglycan	Oligotrophic to eutrophic, benign to harsh environments	1, 200–5, 000 (50%)	
Rhodophyceae (red algae)	Chl a, phycobilins	Cellulose	Freshwater species in streams	1, 500–5, 000 (5%)	
Chrysophyceae	Chl a, Chl c, carotenoids	Chrysolaminarin	Freshwater, temperate, plankton	300–1, 000 (80%)	
Bacillariophyceae (diatoms)	Chl a, Chl c carotenoids	Silica frustules	Plankton and benthos	5, 000–12, 000 (20%)	
Dinophyceae	Chl a, Chl c carotenoids	Cellulose	Primarily planktonic	230–1, 200 (7%)	
Euglenophyceae	Chl a, Chl b	Protein	Commonly in eutrophic waters, associated with sediments	400–1, 000	
Chlorophyceae (green algae)	Chl a, Chl b	Naked, cellulose, or calcified	Oligotrophic to eutrophic, planktonic to benthic	6, 500–20, 000 (87%)	
Charophyceae	Chl a, Chl b	Cellulose, many calcified	Benthic, still to slowly flowing water	315 (95%)	

Table 2.7 List of phytoplankton observed in different study sites in and around six rivers of South West Bengal, India

Sl.No.	Species	Kansai			Keleghai		Subarnarekha		Shilabati			Rupnarayan			Dwarkeswar					
		S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19
1.	*Diatoma* sp.	+	+	+	+	+	–	–	+	+	+	–	–	–	+	+	+	+	+	+
2.	*Fragilaria* sp.	+	+	+	–	+	+	+	–	+	+	–	–	+	+	–	+	+	+	–
3.	*Gomphonema* sp.	+	+	–	+	+	+	+	+	–	+	+	–	+	+	+	–	–	+	+
4.	*Gyrosigma* sp.	+	+	–	+	–	+	+	+	+	+	+	+	–	+	–	–	+	–	–
5.	*Pinnularia* sp.	+	–	–	+	+	–	+	+	+	–	+	+	+	+	+	–	–	+	+
6.	*Stauroneis* sp.	+	+	+	+	–	+	–	–	–	+	–	+	–	+	+	+	–	–	–
7.	*Synedra* sp.	–	+	–	+	–	–	+	+	+	+	–	–	+	+	+	+	+	+	+
8.	*Chlamydomonas* sp.	+	+	+	–	+	+	–	–	–	+	–	–	–	+	+	+	+	–	+
9.	*Closterium* sp.	+	–	+	+	–	+	+	+	+	–	+	–	+	–	–	+		+	+
10.	*Cosmarium* sp.	+	+	–	+	+	+	+	–	+	–	–	–	–	+	–	+	+	+	++
11.	*Oedogonium* sp.	+	–	+	–	+	–	+	–	+	–	+	–	+	–	+	–	+	–	+
12.	*Pandorina* sp.	+	+	–	–	+	–	+	–	+	–	–	–	–	–	–	–	+	–	–
13.	*Spirogyra* sp.	–	+	+	–	+	–	+	+	+	+	–	+	–	+	+	–	+	+	+
14.	*Volvox* sp.	+	+	–	+	+	+	+	+	+	–	+	–	+	+	+	+	+	–	+
15.	*Zygnema* sp.	–	+	+	+	+	+	+	+	–	+	–	+	+	+	+	+	+	+	–
16.	*Anabaena* sp.	+	+	+	+	+	–	–	+	+	+	–	–	–	+	+	+	+	+	+
17.	*Chroococcus* sp.	+	+	+	–	+	+	+	–	+	+	–	–	+	+	–	+	+	+	–
18.	*Lyngbya* sp.	+	+	–	+	+	+	+	+	–	+	+	–	+	+	+	–	–	+	+
19.	*Nostoc* sp.	+	+	–	+	–	+	+	+	+	+	+	+	–	+	–	–	+	–	–
20.	*Oscillatoria* sp.	+	–	–	+	+	–	+	+	+	–	+	+	+	+	+	–	–	+	+
21.	*Phormidium* sp.	+	+	+	+	–	+	–	–	–	+	–	+	–	+	+	+	–	–	–
22.	*Spirulina* sp.	–	+	–	+	–	–	+	+	+	+	–	–	+	+	+	+	+	+	+
	Class: Dynophyceae																			
23.	*Ceratium* sp.	+	+	+	–	+	+	+	–	+	+	–	–	+	+	–	+	+	+	–

(continued)

Table 2.7 (continued)

Sl.No.	Species	Kansai			Keleghai		Subarnarekha		Shilabati			Rupnarayan			Dwarkeswar					
		S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19
24.	*Peridinium* sp.	+	+	–	+	+	+	+	+	–	+	+	–	+	+	+	–	–	+	+
25.	*Euglena* sp.	+	+	–	+	+	+	+	–	+	–	–	–	–	+	–	+	+	+	++
26.	*Phacua* sp.	+	–	+	–	+	–	+	–	+	–	+	–	+	–	+	–	+	–	+
27.	*Trachelomonas* sp.	+	+	–	–	+	–	+	–	+	–	–	–	–	–	–	–	+	–	–
28.	*Chlorobotrys* sp.	–	+	+	–	+	–	+	+	+	+	–	+	–	+	+	–	+	+	+
29.	*Ophiocytium* sp.	+	+	–	+	+	+	+	+	+	–	+	–	+	+	+	+	+	–	+

Table 2.8 List of zooplanktonic species as observed in six rivers of South West Bengal, India

Sl. No.	Species with systematic position	Dwarakeswar	Shilabati	Rupnarayan	Kansai	Keleghai	Subarnarekha
	Phylum: Rotifera						
	Super class: Eurotatoria Bartos, 1959						
	Class: Monogononta Wesenberg-Lund, 1889 Order: Ploimida Delage, 1897						
	Family: Brachionidae Wesenberg-Lund, 1899						
1.	*Beauchampiella eudactylota* (Gosse, 1886)		+				
2.	*Brachionus angularis (Gosse, 1851)*	+	+	+	+	+	
3.	*B. bidentata jirovci (Bartos, 1964)*	+	+				
4.	*B. calyciflorus f. amphiceros*			+			
5.	*B. calyciflorus f. anuraeiformis (Brehm, 1909)*	+					
6.	*B. calyciflorus f. borgerti (Apstein, 1907)*	+					
7.	*B. calyciflorus f. dorcus (Gosse, 1851)*	+					
8.	*B. caudatus personatus (Ahlstrom, 1940)*	+	+			+	
9.	*B.forficula forficula Wierzejski, 1891*						
10.	*B. falcatus Zacharias, 1893*	+			+		
11.	*B. patulus patulus Muller, 1776*		+		+	+	+
12.	*B. quadridentatus brevispinus (Ehrenberg, 1832)*	+					
13.	B. quadridentatus quadridentatus *Hermann, 1783*	+	+				
14.	*B. quadridentatus rhenanus (Lauterborn, 1893)*	+					
15.	*B. rubens Ehrenberg*, 1838	+	+	+	+	+	
16.	*Keratella cochlearis* (Gosse, 1851)	+	+				
17.	*Keratella tropica* Apstein, 1907	+	+	+	+	+	+
18.	*Platyias quadricornis* (Ehrenberg, 1838)				+		
	Family: Euchlanidae Bartos, 1959						
19.	Euchlanis dilatata *Ehrenberg, 1832*		+	+			+

(continued)

Table 2.8 (continued)

Sl. No.	Species with systematic position	Dwarakeswar	Shilabati	Rupnarayan	Kansai	Keleghai	Subarnarekha
	Family: Mytilinidae Bartos, 1959						
20.	*Mytilina ventralis ventralis (Ehrenberg, 1832)*					+	
	Family: Trichotridae Bartos, *1959*						
21.	*Trichotria tetractis* (Ehrenberg, 1832)	+	+				+
	Family: Colurellidae Bartos, 1959						
22.	*Colurella uncinata (Muller, 1773)*		+				
23.	*Lepadella (Lepadella) ovalis ovalis (Muller, 1786)*					+	
	Family: Lecanidae Bartos, 1959						
24.	*Lecane (Lecane) crepida crepida Harring, 1914*		+				
25.	*L. (L) curvicornis curvicornis* (Murray, 1913*)*				+		
26.	*L. (L) hastata (Murray, 1913)*		+				
27.	*L.(L) hornemanni (Ehrenberg, 1834*				+	+	
28.	*L. (L) leontina (Turner, 1892)*		+				
29.	*L. (L) luna luna (Mullar, 1773)*			+			
30.	*L. (L) nana (Murray, 1913)*	+					
31.	*L. (L) papuana (Murray, 1913)*	+					+
32.	*L.(L) ungulata (Gosse, 1887)*		+				
33.	*Lecane (Monostyla) bulla* (Gosse, 1851)	+	+	+			
34.	*L. (M) decipiens* (Murray, 1913)	+					
35.	*L. (M) hamata (Stokes, 1896)*	+					+
36.	*L. (M) lunaris lunaris (Ehrenberg, 1830)*	+	+		+		
37.	*L.(M) pyriformis* (Daday, 1905)		+				
38.	*L. (M) stenroosi (Meissner, 1908)*	+					
	Family: Notommatidae Remane, 1933 (partim)						
39.	*Cephalodella gibba* (Ehrenberg, 1832)	+					+

	Family: Trichocercidae Remane, 1933						
40.	*Trichocerca (Trichocerca) elongata braziliensis* (Murray, 1913)		+				
41.	*T. (T) pusilla* (Lauterborn, 1898)		+				
42.	*T.(T) rattus* (Muller, 1776)		+				
	Family: Asplanchnidae Harring & Myers, 1926						
43.	*Asplanchna priodonta* Gosse, 1850	+	+	+	+	+	+
	Family: Synchaetidae Remane, 1933						
44.	Polyarthra vulgaris *Carlin, 1943*	+	+	+	+	+	+
	Order: Gnesiotrocha De Beauchamp, 1965						
	Family: Testudinellidae Bartos, 1959						
45.	*Pompholyx sulcata* Hudson, 1885				+		
	Family: Filinidae Bartos, 1959						
46.	Filinia longiseta (Ehrenberg, 1834)	+	+		+		+
47.	*F. terminalis* (Plate, 1886)	+				+	
	Superclass: Crustacea						
	Class: Branchiopoda						
	Subclass: Diplostraca						
	Order: Cladocera						
	Suborder: Anomopoda						
	Family: Daphniidae						
1.	*Ceriodaphnia cornuta*			+		+	+
2.	*Daphnia lumholtzi*				+	+	
3.	*Scapholeberis kingi*				+		
	Family: Moinidae						
4	*Moina micrura*	+	+	+	+	+	
	Family: Bosminidae						
5.	*Bosmina* sp.		+	+	+	+	

(continued)

Table 2.8 (continued)

Sl. No.	Species with systematic position	Dwarakeswar	Shilabati	Rupnarayan	Kansai	Keleghai	Subarnarekha
6.	*Bosminopsis deitersi*		+	+			+
	Family: Macrothricidae						
7.	*Macrothrix* sp.	+	+				
	Family: Chydoridae						
8.	*Alona affinis*	+			+		
9.	*Alona intermidia*	+				+	+
10.	*Chydorus sphaericus*			+			
11.	*Leydigia* sp.				+		+
	Family: Sididae						
12.	*Diaphanosoma* sp.				+		+
	Class: Crustacea						
	Subclass: Copepoda						
	Order: Cyclopoida						
	Family: Cyclopidae						
1.	*Eucyclops serrulatus* Fischer, 1851	+	+		+	+	
2.	**Mesocyclops thermocyclopoides *Harada, 1913***	+		+		+	
3.	*Microcyclops varicans* Gurney, 1933		+				+
	Order: **Calanoida**						
	Family: Diaptomidae						
4.	*Heliodiaptomus viduus* (Gurney, 1916)		+		+		
5.	*Heliodiaptomus cinctus* (Gurney, 1907)		+				+
6.	*Heliodiaptomus nipponicus* (Kokubo, 1914)	+		+		+	+

Table 2.9 Similarity indices of zooplankton species among six rivers of South West Bengal, India (result expressed in %)

	Dwarkeswar	Shilabati	Rupnarayan	Kansai	Keleghai	Subarnarekha
Dwarkeswar		48.48	36.73	40.00	46.15	39.21
Shilabati			40.81	43.63	38.46	39.21
Rupnarayan				36.84	57.14	41.17
Kansai					53.66	35.00
Keleghai						37.83
Subarnarekha						

vegetation, associated animals, water, and soils (Malanson, 1993). Riparian forests are located on land adjacent to water bodies which are subjected to periodical inundation by flooding (Mitsch and Gosselink, 2000) and, thereby, make the vegetation adaptive to the inundation pressure of elevated water tables and facilitate the soils to develop ability to hold water (Naiman 1997).

The riparian zone is also supported by recent fluvial landforms such as floodplains, riparian wetlands, channels and banks, and fluvial landforms below the bank-full elevation, and all of such unique landscapes experience frequent inundation by the bank-full discharge and flood mediated run off (Hupp and Osterkamp, 1996; Osterkamp and Hupp 2010). Several ecological and hydro-geological processes interact strongly within riparian zones giving rise to a highly dynamic but heterogeneous landscape habitats structured by strong flow energy gradient (Hupp, 1999; Hughes and Petchey 2001).

Mineral sediments and organic matter of water after being driven by flows of water triggers the morphodynamics of these ecozones which in turn govern their ecology through the associated transfer of organisms and nutrients. Such riverine hydrodynamics also trigger the development of hydrological connectivity (Amoros and Roux 1988) which in turn ensures the water-driven exchange of matter and energy among different geomorphological components of the riverine landscape (Ward et al. 2002). The hydrological connectivity involves the lateral connectivity between the river and its floodplain, longitudinal connectivity between upstream and downstream of river systems, and vertical connectivity between surface water bodies and groundwater in the alluvial aquifer and underlying bed rock (Ward 1989; Ward et al. 2002; Gurnell et al. 2000, 2012). Besides, important feedbacks are developed because of the continuous interactions between different forms of vegetation and fluvial processes, which in turn influence the mode of impacts and shape the ecological characteristics and dynamics of the riparian habitat mosaic (Corenblit et al. 2011). Such complexity and dynamics within a naturally functioning riparian system ultimately result in higher biodiversity and biological production (Naiman 1997; Ward et al. 1999; Tockner and Stanford 2002).

The riparian systems provide refugia and dispersal pathways for species by acting as important ecological corridors (Ward and Stanford, 1995; Naiman 1997), attenuate floods and control water balances by arresting the flows of runoff and increasing rates of both infiltration and evapotranspiration (Nilsson et al. 1997; Crockford and Richardson, 2000; Steiger et al. 2005; Anderson et al. 2006), enhance the quality of

Table 2.10 List of mollusks observed in sampling sites in and around six rivers of South West Bengal, India

Sl. No.	Order, family, and species	Kansai			Keleghai		Subarnarekha		Shilabati			Rupnarayan			Dwarkeswar					
		S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19
	Class: **Gastropoda**																			
	Order: **Mesogastropoda**																			
	Family: Thiaridae																			
1.	*Thiara (tarabia)lineata* (gray)	+	+	+	+	–	+	+	+	+	+	+	+	+	+	+	+	+	+	+
2.	*Thiara (Melanoides) tuberculata* (Muller)	+	+	+	+	–	+	+	+	+	+	+	+	+	+	+	+	+	+	+
3.	*Thiara (tarabia) granifera* (Lamarck)	+	–	+	+	–	+	+	+	+	+	–	–	–	+	+	+	+	+	+
	Family: Viviparidae																			
4.	*Bellamya bengalensis* (Lamarck)	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
	Family: **Bithyniidae**																			
5.	*Digoniostoma cerameopoma* (Benson)	+	+	+	+	+	+	+	+	+	+	–	–	–	+	+	+	+	+	+
6.	*Gabbia orcula* (Frauenfeld)	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
	Order: Basommatophora																			
	Family: Lymnaeidae																			
7.	*Lymnaea (Pseudosuccinea) luteola* (Lamarck)	+	+	+	+	+	+	+	+	+	+	+	–	–	+	+	+	+	+	+
	Family: Planorbidae																			
8.	*Indoplanorbis exustus* (Deshayes)	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
9.	*Gyraulus convexiusculus (Hutton)*	+	+	+	+	+	+	+	+	+	+	+	–	+	+	+	+	+	+	+

	Family: Pilidae																			
10	*Pila globosa* (Swainson)	+	+	+	+	+	+	+	+	+	+	–	–	+	+	+	+	+	+	+
	Class: **Bivalvia**																			
	Order: **Unionida**																			
	Family: **Unionidae**																			
11	*Parreysia* sp.	+	+	+	+	–	+	+	+	+	+	+	+	+	+	+	+	+	+	+
12.	*Lamellidens marginalis* (Lamarck)	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
	Order: **Veneroida**																			
	Family: Corbiculidae																			
13.	*Corbicula striatella* (Deshayes)	+	+	+	+	+	+	+	+	+	+	–	–	–	+	+	+	+	+	+

Table 2.11 Distribution and relative abundance of molluskan species in selected study sites of Subarnarekha River, South West Bengal, India

Sl. No.	Family	Species	Study site I		Study site II		Study site III		Study site IV		Study site V	
			RA	Rank	RA	Rank	RA	Rank	RA	Rank	RA	Rank
1	Viviparidae	*Bellamya bengalensis* (Lamarck, 1822)	13.06***	2	12.21***	2	**33.01*****	1	**35.39*****	1	0.88*	14
2		*Bellamya dissimilis* (Muller 1774)	–		–		8.05***	6	13.51***	3	–	
3	Thiaridae	*Taberia granifera* (Lamarck, 1822)	8.67***	3	9.86***	3	9.76***	5	–		–	
4		*Thiara scabra* (Muller, 1774)	**69.47*****	1	**51.03*****	1	13.66***	2	15.39***	2	2.47*	6
5		*Thiara lineate* (gray)	–		8.33***	6	8.03***	7	8.37***	5	–	
6	Lymnaeidae	*Lymanea acuminata* (Lamarck, 1822)	6.80***	4	8.61***	4	10.03***	3	–		–	
7		*Lymnaea luteola* (Lamarck, 1822)	–		8.39***	5	9.91***	4	12.21***	4	–	
8	Unionidae	*Lamellidens corrianus* (Lea, 1834)	–		–		3.87**	8	3.52**	8	–	
9		*Lamellidens marginalis* (Lamarck, 1819)	1.98*	5	1.51*	7	3.65**	9	3.53**	7	–	
10	Corbiculida	*Corbicula peninsularis* (Prashad 1928)	–		–		–		5.64***	6	1.65*	
11		*Corbicula striatella* (Deshayes, 1854)	–		–		–		2.41*	9	1.66*	

12	Assimineidae	*Assiminea brevicula* (Pfeiffer)	–		–		–		–		9.9***	3
13	Littorinidae	*Littorina (Littoraria) melanostoma* gray	–		–		–		–		2.87**	4
14	Potamididae	*Telescopium telescopium* (Linnaeus)	–		–		–		–		30.40***	2
15		*Cerithidea cingulata* (Gmelin)	–		–		–		–		**34.47*****	**1**
16		*Cerithidea obtusa* (Lamarck)	–		–		–		–		2.40*	7
17	Naticidae	*Natica tigrina* (Roeding)	–		–		–		–		2.71**	5
18	Onchidiidae	*Onchidium tigrinum* (Stoliczka)	–		–		–		–		1.72*	12
19	Arcidae	*Anadara granosa* (Linnaeus)	–		–		–		–		1.79*	9
20	Mytilidae	*Perna viridis* (Linnaeus)	–		–		–		–		1.76*	10
21		*Modiolus undulates* (Dunker)	–		–		–		–		1.75*	11
22		*Modiolus striatulus* (Hanley)	–		–		–		–		1.97*	8
23	Veneridae	*Meretrix meretrix* (Linnaeus)	–		–		–		–		1.57*	13

*** = dominant (>5%), ** = subdominant (>2.5%), * = rare (<2.5)

Table 2.12 List of aquatic insects as observed in and around different ecozones of six rivers of South West Bengal, India

Sl. No.	Order, family, and Species	Kansai			Keleghai		Subarnarekha		Shilabati			Rupnarayan			Dwarkeswar					
		S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19
	Order: Hemiptera																			
	Family: Nepidae																			
1.	*Ranatra elongata* (Fabricius)	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
2.	*Ranatra sordidula* (Dohrn)	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
3.	*Laccotrephes* sp.	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
4.	*Laccotrephes griseus* (Guerin)	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
	Family: Belostomatidae																			
5.	*Diplonychus annulatus* (Fabricius)	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
6.	*Diplonychus* sp.	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
	Family: Corixidae																			
7.	*Microneta* sp.	+	+	+	+	+	+	+	+	+	+	–	–	–	+	+	+	+	+	+
	Family: Scutellenidae																			
8.	*Chrysocoris* sp.	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
	Family: Gerridae																			
9.	*Gerris spinolae* (Lath & Serv)	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
	Family: Notonectidae																			
10.	*Anisops sardea* (Herrich-Schaeffer)	+	+	+	+	+	–	–	+	+	–	–	–	–	–	–	–	–	–	–
	Order: Orthoptera																			
	Family: Gryllidae																			
11	*Plebeiogryllus* sp.	+	+	+	+	+	+	+	+	+	+	–	–	–	+	+	+	+	+	+

	Family: Pyrgomorphidae																			
12.	*Atractomorpha crenulata* (Fabricius)	+	+	+	+	+	+	+	+	+	+	–	–	–	+	+	+	+	+	+
13.	*Chrotogonus tretrachypterus* (Bl.)	+	+	+	+	+	+	+	+	+	+	–	–	–	+	+	+	+	+	+
		S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19
	Family: Tridactylidae																			
14.	*Xya* sp.	+	+	+	+	+	+	+	+	+	+	–	–	–	+	+	+	+	+	+
	Family: Tetrigidae																			
15.	*Thoradonta bengalensis* (Shishodia)	+	+	+	+	+	+	+	+	+	+	–	–	–	+	+	+	+	+	+
	Order: Dermaptera																			
	Family: Labiduridae																			
16.	*Nala liviclipes* (Dufour)	+	+	+	+	+	+	+	+	+	+	–	–	–	+	+	+	+	+	+
17.	*Euborellia* sp.	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
	Order: Odonata																			
	Suborder: Anisoptera																			
	Family: Libellulidae																			
18.	*Libellulid* sp.	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
	Family: Gomphidae																			
19.	*Gomphid* sp.	+	–	–	–	–	+	+	+	+	+	–	–	–	+	+	+	+	+	+
	Order: Dictyoptera Family: Blattellidae																			
20.	*Blattella* sp.	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+

Table 2.13 List of oligochaete species as recorded in different ecozones in and around six rivers of South West Bengal, India

Sl. No.	Order	Family	Name	Kansai			Keleghai		Subarnarekha		Shilabati			Rupnarayan			Dwarkeswar					
				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
	Haplotaxida	Megascolecidae																				
1.			*Perionyx excavatus*	+	+	+	–	–	+	+	+	+	+	+	+	+	+	+	+	–	+	+
2.			*Lampito mauritii*	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
3.			*Metaphire posthuma*	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
4.			*Metaphire planata*	+	–	+	+	+	–	–	–	–	–	–	–	–	+	–	–	+	+	–
5.			*Metaphire houlleti*	+	–	+	+	+	–	–	+	–	–	+	+	+	+	–	–	+	+	–
6.			*Polypheretima elongata*	+	–	+	–	–	–	–	+	+	+	–	–	–	+	–	+	+	+	–
7.			*Amynthas alexandri*	+	–	+	–	–	–	–	+	+	–	+	+	+	+	–	+	+	+	–
		Octochaetidae																				
8.			*Octochaetona surensis*	+	–	+	–	–	+	+	–	–	–	–	–	–	+	+	+	+	+	+
9.			*Octochaetona beatrix*	+	–	+	–	–	+	+	–	–	–	–	–	–	+	+	+	+	+	+
10.			*Octochaetona compta*	–	–	+	–	–	+	+	–	–	–	–	–	–	–	–	–	–	–	–
11.			*Eutyphoeus kherai*	+	+	+	–	–	–	–	+	+	+	+	+	+	+	+	+	+	+	+
12.			*Dichogaster modiglianii*	+	+	+	–	–	–	–	–	+	+	–	–	–	+	+	+	+	+	+

		Ocnerodrilidae																				
13.			*Malabaria biprostata*	–	+	+	–	–	–	–	–	–	–	+	+	+	–	–	–	–	–	–
14.			*Decania Alba*	+	–	+	–	–	+	+	–	–	–	–	–	–	+	+	+	+	+	–
		Almidae																				
15.			*Glyphidrilus tuberosus*	+	+	+	+	+	–	–	–	–	–	+	+	+	+	–	+	+	+	+
		Glossoscolecidae																				
16.			*Pontoscolex corethrurus*	+	+	+	–	–	+	+	+	+	+	–	–	–	+	+	+	+	+	+
	Moniligastrida	Moniligastridae																				
17.			*Drawida limella*	–	–	–	–	–	+	+	–	–	–	–	–	–	–	–	–	–	–	–

Table 2.14 List of crustacean (decapods) species as recorded from different ecozones in and around six rivers of South West Bengal, India

Sl. No.	Order, family, and species	Kansai			Keleghai		Subarnarekha		Shilabati			Rupnarayan			Dwarkeswar					
		S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19
	Order: **Decapoda**																			
	Suborder: Macrura																			
	Family: **Palaemonidae**																			
1.	*Macrobrachium rosenbergii* (de.Man)	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
2.	*Macrobrachium lamarrei* (H.M. Edwards)	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
3.	*Macrobrachium dayanum* (Henderson)	+	–	–	+	–	+	+	+	+	+	–	–	–	+	+	+	+	+	+
4.	*Macrobrachium malcomsonii* (H.M. Edwards)	+	–	–	+	–	+	+	+	+	+	+	+	+	+	+	+	+	+	+
5.	*Macrobrachium scabriculum* (Hells)	+	+	+	+	–	+	+	+	+	+	–	–	–	+	+	+	+	+	+
6.	*Macrobrachium idella* (Hilgendorf)	+	–	–	+	–	+	+	+	+	+	+	+	+	+	+	+	–	–	–
7.	*Palaemon (exopalaemon) styliferus* (H.M. Edwards)	+	–	–	+	–	–	+	–	–	+	+	+	+	–	–	–	+	–	+
	Family: **Atyidae**																			
8.	*Caridina* sp.	+	+	+	+	–	+	+	+	+	+	+	+	+	–	+	–	+	+	–
	Family: **Penaeidae**																			
9.	*Penaeus semeweatus* (de.Man)	+	–	–	+	–	–	–	+	+	+	+	+	+	–	+	–	+	–	–
10	*Metapenaeus monoceros* (Fabricius)	+	–	–	+	–	–	+	–	+	+	+	+	+	–	+	+	+	+	–
11.	*Metapenaeus lysianassa* (de. Man)	+	–	–	+	–	–	+	–	–	+	+	+	+	–	–	–	+	+	+

Table 2.15 Major faunal groups inhabiting rivers and their associated aquatic ecosystems

Phylum Porifera	Class Branchiopoda
Phylum Cnidaria	Order Notostraca
Phylum Platyhelminthes	Order Anostraca
Class Turbellaria	Order Conchostraca
Phylum Nemertea	Order Cladocera
Phylum Gastrotricha	
Phylum Nematoda	Class Malacostraca
	Subclass Eumalacostraca
	Superorder Peracarida
	Order Amphipoda
	Superorder Syncarida
	Order Anaspidacea
	Order Bathynellacea
	Superorder Pancarida
	Order Thermosbaenacea
	Superorder Eucarida
	Order Decapoda
	Subphylum Uniramia
Phylum Nematomorpha	Class Insecta
Phylum Rotifera	Subclass Entognatha
Phylum Bryozoa	Order Collembola
Phylum Tardigrada	Subclass Entognatha
Phylum Mollusca	Order Odonata
Class Bivalvia	Order Ephemeroptera
Class Gastropoda	Order Plecoptera
Phylum Annelida	Order Hemiptera
Class Polychaeta	Order Neuroptera
Class Oligochaeta	Order Trichoptera
Class Hirudinea	Order Lepidoptera
Phylum Arthropoda	Order Diptera
Subphylum Chelicerata	Order Coleoptera
Class Arachnida	
Subclass Acari	
Order Prostigmata	
Subphylum Crustacea	
Class Copepoda	
Order Calanoida	
Order Harpacticoida	
Order Cyclopoida	
Class Branchiura	
Class Ostracoda	

Source: Adapted from Ruppert and Barnes (1995) and Palmer and Lake (2001) water by intercepting fine sediments and pollutants, and promote cycling of inorganic nutrient and organic matter (Osterkamp and Hupp, 2012).

2.22.1.2 Submerged Aquatic Vegetation (SAV)

2.22.1.2.1 Characteristics and Ecological Roles of Macrophytes

Macrophytes, being the large-sized aquatic plants observable by the naked eye, can be classified into four categories: (**1**) free-floating, (**2**) floating-leaved, (**3**) emerged, and (**4**) submerged.

These four groups of macrophytes are defined by their connection to the water body substrate (**Fig. 2.5**) Free-floating macrophytes mainly remain just under the water surface having their roots immersed within the water column. They absorb nutrients entirely from the water column. Floating-leaved macrophytes are rooted to the bottom with leaves that float on the water surface. They may also have underwater leaves. Emerged macrophytes grow near the banks of surface waters, typically in depths of around **1** m of water.

They have their basal portions submerged in water and have their upper structural biomass growing in the air. Submerged macrophytes, also called submerged aquatic vegetation (**SAV**), are a diverse group that grows completely (for the most part) under the water. The definition of **SAV** usually excludes algae, floating plants, and plants that grow above the water surface. Macrophytes can inhibit phytoplankton growth by competing for nutrients. During the ecologically favorable seasons (spring and summer) accelerating the growth and propagation, **SAV** consumes large quantities of nutrients, which are used for developing their biomass throughout the warm seasons.

Nutrients are slowly released back into the water column after the death and decomposition of **SAV.** Through their different biologic and metabolic activities, such as primary production and respiration, **SAV** also determines the **DO** and $\mathbf{CO_2}$ concentrations, alkalinity, and **pH** of the water body. Submerged aquatic vegetation also plays great roles in stabilizing sediments by arresting and binding the sediments to the bottom with their roots and vegetative parts of the body by retarding water currents; **SAV** allows suspended sediments to settle down and thereby to improve the clarity and transparency of water.

In the absence of **SAV**, sediments, along with the nutrients, are easily resuspended from the bottom causing algal blooms.through nutrient enrichment and also, inhibiting the availability of light needed for photosynthesis by the phytoplankton in the different strata of water column. By way of minimizing erosion, **SAV** also protects the shoreline. Submerged aquatic vegetation provides suitable habitats for several benthos, periphytons, fish, wading birds, and other wildlife by producing oxygen, supplying nutrients, and providing shelter. Not all healthy surface waters have the physical and chemical properties necessary to support **SAV**. Key factors that control **SAV** growth include (**1**) light availability, (**2**) nutrients, (**3**) substrate characteristics, and (**4**) temperature.

2.22.1.2.2 Eco-physiological Requirements of Macrophytes

Submerged aquatic vegetation species require **20%** of daily incident light for their survival in comparison with phytoplankton, which require only **1%** of daily incident light (Dennison et al. 1993; Kenworthy and Haunert, 1991). Excessive nutrients stimulate algal blooms in the water column and reduce water clarity by overcrowding of biomass triggering a thick growth of epiphytes that prevent the sunlight from reaching the leaf surfaces. As the light availability decreases, the **SAV** density decreases, leading to fewer nutrients consumed by **SAV** and the increased possibility of algal blooms which in turn pose competition with algae for nutrients. Nutrients are also released into the overlying water, after the death, decay, and decomposition of **SAV** tissue.

2.22.1.3 Diversity of Macrophytes in the Riverine Networks of South West Bengal, India

Considering the importance of aquatic and semiaquatic macrophytes in maintaining the ecological stability, promoting the enhancement of biodiversity, and ensuring ecological balance within aquatic ecosystems (Ryszkowski, 1975), several studies have been made on macrophytic diversity in different lentic freshwater bodies of India, but very scanty information are available on the diversity, distribution, and density of macrophytes of rivers from the riverine tracts of South West Bengal, India, excepting a comprehensive ecological study of macrophytes by Pradhan et al. (2005).

A recent study was made to document the species composition and seasonal distribution of different macrophytes in selected study sites on six rivers in South West Bengal, India, viz., Subarnarekha, Rupnarayan, Dwarakeswar, Shilabati, Kansai, and Keleghai, in relation to the soil and water qualities of aquatic environments along the stretch of six rivers. A water body was considered as live when it harbors organisms, both plants and animals, and promotes recycling of their life processes within the system.

Obviously, dominance of the macrophytes within the riverine ecosystem was also reflected by their multifarious roles towards facilitating the aquatic productivity process. Those biotic components synthesize basic organic elements like protein, fat, and carbohydrate and ultimately contribute to the detritus pool of the bottom soil after their decay and death. Handoo et al. (1988) made an attempt to estimate the energy capturing efficiency of **17** dominant macrophytic species belonging to **3** different life-form classes in various basins of Dal Lake, Kashmir, India. They act as substrates for periphytic growth, provide shelter to different aquatic fauna, and also serve as breeding ground for the associated fauna. Macrophytes and their associates thus constitute a prime contributor in the formation of food chains of water bodies and also to maintain linkages among them.

All total **84** macrophytic species belonging to **73** genera and **34** families were recorded during this study spanning a period of **2** continuous years (Table 2.1;

Fig. 2.5). Among these, **55** terrestrial plants species **(66%)** belonging to **48** genera and **25** families, **11** aquatic plants species (**13%**) belonging to **9** genera and 8 families, and **18** semiaquatic plants species (**21%**) belonging to **16** genera and **13** families were found to occur in different studied water bodies (Pradhan et al. 2005).

There were differences in vegetation composition in response to different ecological conditions of the water body (Kaul and Handoo, 1989; Hutchinson 1969). Free flowing rivers represent one of the most dynamic systems among different aquatic ecosystems. Difference in landscape coupled with physical (current, waves, depth, density, etc.) and chemical characteristics (**pH**, dissolved oxygen, total dissolved solid, chemical oxygen demand, etc.) create different types of fluvial environments (Celwell et al. 1999; Gregory, et al. 1991; Malanson, 1993). Species composition of aquatic vegetation changes from site to site in a riverine system in tune with the hydrodynamics and sediment characteristics (Cathleen et al. 2001), which has been corroborated by the present findings.

Besides, not only the diversity but the adaptability in respect of dispersal patterns of the floral components can generate information pertaining to the floristic patterns along rivers, both for species (Staniferth and Cavers, 1976) and communities (Nilsson et al. 1991, Schaneider and Sharitz, 1988). A large river having considerable width coupled with feeble currents enables the propagules of plants to float for longer duration prior to becoming settled, established, and germinate (Nilsson et al. 2002).

However, in the rivers having higher water current, floating ability of the seeds of plants diminishes (Danvind and Nilson, 1997). Dependence of seeds stranding on hydraulic factors such as turbulent waves was established by Nepf (1999). The same study shows the maximum and minimum occurrence of macrophytes in Subarnarekha River as **52** species and **20** species, respectively. Such differences in the species richness are thought to be due to the occurrence of low current and wide floodplain in Subarnarekha River, while the Rupnarayan is characterized by high current experiencing tidal influence.

Similarity indices, in respect of all vegetation types, terrestrial, aquatic, and semiaquatic, inhabiting the six rivers and their adjoining water bodies are represented separately in Tables 2.2, 2.3, 2.4 and 2.5. Similarity indices in respect of vegetation covering six rivers revealed that only in six cases percentage of similarities were above **90%** [Dwarkeswar and Shilabati (**94.3%**); Dwarkeswar and Kansai (**99.4%**); Dwarkeswar and Subarnarekha (**95.6%**); Shilabati and Kansai (**97.5%**); Shilabati and Subarnarekha (**94.9%**); and Kansai and Subarnarekha (**97.5%**)]. The percentage of similarities were below **60%** only in two cases [Dwarakeswar and Rupnarayan (**57.4%**); Rupnarayan and Keleghai (**57.4%**)] (Pradhan et al. 2005).

The aquatic plants from Dwarkeswar and Kansai River showed 100% similarities. The same trend (**100%** similarity) was found among semiaquatic plants of Kansai and Shilabati, Shilabati and Subarnarekha, and Kansai and Subarnarekha. The results highlighted the differences in vegetation patterns in response to different ecological conditions of the riverine tracts (Pradhan et al. 2005).

Most of the river networks on receiving profuse quantity of rainfall especially during monsoon become water saturated which provides the plant species conducive ecological conditions to grow and propagate. This seasonal flourishing of plant biomass ultimately enriches the soil and water of rivers during postmonsoon months through the process of decomposition (Trisal, 1987).

Besides this, macrophytes contribute in a significant manner to the reduction of fecal coliform and other pathogens (Wu et al. 1993). As a result, macrophytes have received much attention in recent years as an important biofilter agent (Pandit, 1984). Simultaneously, it is known that free-floating macrophytes remove nutrients from the water; especially rooted submerged macrophytes absorb most of the available phosphorus from the water (Kaul and Pandit, 1980). Kaul et al. (1980) further opined that the macrophytes growing in the eutrophicated Dal Lake are highly efficient in the removal of **N**, **Ca**, and **K** from the nutrient pool. The macrophyte-associated fauna being an important link in the food web of the aquatic ecosystem plays a vital role in the fish production from these water bodies (Mitra, 1997).

Freshwater macrophytes enrich the detritus pool of the bottom soil which in turn supports a good bottom macro-invertebrate fauna mainly of mollusks (Sharma et al. 2001). Freshwater macrophytes enrich the detritus pool of the bottom soil which in turn supports a good bottom macro-invertebrate fauna mainly of mollusks (Sharma et al. 2001). Aquatic macrophytes support massive colonization of macro-invertebrate fauna by providing them food, shelter, breeding ground and rearing area for their progenies. Bulk of this fauna comprises the ubiquitous mollusks, followed by nymphs, larvae and adults of insects, annelids, ostracods, crustaceans, etc. The higher abundances of benthos during postmonsoon and pre-monsoon months are supposed to because of higher rigorosity, and less stability of the habitats due to torrential rains, higher speed of currents of water loaded with maximum suspended solids, difficulty in procuring foods and nutrients, etc. during monsoon.

The benefits of ecological changes during monsoon are found during post- and pre-monsoon because of higher water volume loaded with nutrients and plankton, growth of green plants, and their associated biota in land–water interphase. The diversity, colonization, propagation, and density of the faunal components which depend on the aquatic macrophytes mainly for food and shelter exhibit variation after being influenced by the variability of the species composition and abundance of macrophytes and seasonal fluctuation of physicochemical properties of the habitat because of the changes of the climatic conditions and hydrobiology of the studied rivers (Tables 2.1, 2.2, 2.3, 2.4 and 2.5; Fig. 2.5).

2.22.2 Phytoplankton and Their Functional Roles

Phytoplankton (from Greek **phytos** meaning plant and **planktos** meaning **drifting**), microscopic unicellular colonies of green plants, form the base of aquatic food webs as the primary producers and as such play vital roles in aquatic ecology.

They also play great roles in determining atmospheric $\mathbf{CO_2}$ cycles and other climatically active gases through their roles in the oceanic and global carbon and nutrient cycles. In most cases, phytoplankton are more important than rooted aquatic vegetations in the basic food production of an ecosystem. They are the most biologically active plants in aquatic ecosystems and generally have a greater influence on water quality than other plants.

Phytoplankton exist in numerous forms and live in nearly all kinds of environments. Algae are grouped based on their adaptability to different ecological parameter conditions, such as temperature, light, and nutrient conditions. Such groups of algae are of three types: (**1**) cyanobacteria (blue-green algae), (**2**) green algae, and (**3**) diatoms (Table 2.6).

Blue-green algae representing very important primary producers in both freshwater and marine systems are actually bacteria, although they possess chlorophyll for photosynthesis. The higher abundance because of prolific growth or blooms of these algae impart blue-green coloration in the water and also produce chemicals forming scum on the water surface that are harmful to both animals and humans and may cause a bad odor and taste in drinking water.

Blue-green algae are known to cause water problems owing to the release of dissolved organic residuals and are generally considered to be objectionable when they occur in large concentrations. Blue-green algae dominate over other algal species and create nuisance or noxious conditions because of the possession of some unique characteristics such as their extreme power of tolerance in environmentally stressed situations, ability to float or sink depending on light conditions, and nutrient supply. Positive buoyancy of the blue-green algae can result in mass accumulations at the surface, depending on the conditions of sunlight, wind speed, and vertical mixing (Ganf, 1974). Green algae exist in diverse sizes, shapes, and growth forms (Table 2.7).

They are dependent on vertical mixing in the water column to cycle them through the euphotic zone. Diatoms are a group of phytoplankton species utilizing silica as a structural component of the cell wall. They depend on water turbulence to remain suspended. Diatoms are generally a preferred phytoplankton group to support higher trophic levels.

In most water bodies, however, phosphorus and nitrogen are the most likely limiting nutrients. In order for algae to grow, both nitrogen and phosphorus must be present. In rivers, lakes, and other freshwater systems, phosphorus concentrations are often low and limit algal growth.

2.22.3 Fungal Diversity

2.22.3.1 Diversity of Endophytic and Benthic Fungi

Endophytes are microorganisms living in the internal tissues of the plants especially aquatic macrophyte. Endophytic fungi represent a diverse nutritional type ranging from biotrophic parasites to facultative saprophytes. Infection of endophytes enhances the defense of host against herbivory from grazing animals (Clay, 1992). Alongside their role as biocontrol agent, this group of microorganism produces different types of novel metabolites which are being used as antibiotic, antidiabetic, and immunosuppressive drugs. A recent research study has documented endophytic fungal assemblage in different parts (leaf, stem, and root) of different plants in different study sites of rivers and riverian basins of South West Bengal, India (Annon, 2014). Three aquatic plants, viz., *Hygrophila auriculata*, *Ipomoea aquatica*, and *Enydra fluctuans*, were selected for detailed study of their endophytic fungi which inhabit an environmental condition having higher humidity, a mean temperature of **32 °C**, and an average annual rainfall of **1200 mm.**

Isolated fungi belonged to **19** fungal genera, including **2** unidentified fungi and 1 yeast. Among all isolated endophytes, *Fusarium* sp., *Curvularia* sp., and *Penicillium* sp. were the most common, whereas *Alternaria, Aspergillus* sp., *Xylaria* sp., *Paecilomyces* sp., and *Pythium* sp. were the least abundant. Differences in the abundance and diversity of endophytic fungi in different study sites are thought to be due to the variation in water quality and physical conditions of aquatic systems in different study sites (Anon, 2014).

The riverian ecosystems are naturally inhabited by a variety of detritivores that exhibited an extensive array of ecological niches where different species of fungi and bacteria used to play a prime role. In this research study, diversity and richness of fungi have been found to have been largely interlinked with physicochemical parameters of water. A total number of **219** fungal strains were recorded after being microscopically visualized and identified, which belonged to **6** genus of which a number of heavy metal-tolerant species (*Aspergillus* sp. and *Penicillium* sp.) were found (Paria et al. 2017). The major fungal species are *Penicillium*, *Aspergillus*, *Pythium*, *Fusarium*, *Rhizopous*, and *Trichoderma*.

2.22.3.2 Distribution and Occurrence of Coliform Bacteria

India is endowed with rich water resources. The water qualities of rivers have undergone considerable deterioration during the last several decades because of the rapidly increasing population, rising standards of living and exponential growth of industrialization and urbanization, etc.

The mode of occurrences and trend of variation in density of coliform bacteria in water bodies enjoys a special status in pollution studies. The coliform bacteria can also be used as indicator pathogenic microbial group in water because of their power of profic growth and wide range of distribution patterns.

The coliform bacteria include a number of species belonging to different genera such as *Escherichia*, *Citrobacter*, *Enterobacter*, *Klebsiella*, *Streptococcus*, *Clostridium*, *Salmonella*, *Shigella*, etc. The coliform group also comprises all of the facultative and aerobic Gram-negative, nonspore-forming rod-shaped bacteria that ferment lactose with gas formation within **48** hours at **37 ° C** (Trivedy and Goel 1984).

The fecal coliform group, which is also being considered as an indicator microbial group, originates in the intestinal tract of human and other animals. The present paper has attempted to record the distributional pattern of the total coliform and fecal coliform bacteria of three estuaries of Sundarbans mangrove–estuarine complex, India, viz. Hooghly, Saptamukhi and Matlah estuaries.

Major physicochemical parameters were also recorded simultaneously in order to establish their relationship with bacterial population and their distributional patterns in different estuaries (Chakravaroty et al. 2004). A recent research survey on the distribution of fecal coliform bacteria from the river networks of three districts of West Bengal, India, viz. Purulia, Bankura, and Midnapore (West), have been conducted which revealed the variation of coliform (fecal and total coliform) bacterial load from season to season and site to site in the different stretches of the river. The average monthly total coliform and fecal coliform bacterial population in the Subarnarekha River during the yearlong investigation were fluctuated from **560** to **2133.33 MPN/I00ml** and from **240 to1373.33 MPN/I00ml**, respectively.

The minimum and maximum monthly densities of total coliform bacteria were recorded as **560MPN/I00ml** in July and **2133.33MPN/I00ml** in March. In general, total count showed a declining trend from May to August, while there was a fluctuating trend throughout the year. The trend of annual fluctuation of total coliform and fecal coliform population in the Subarnarekha River can be represented as maximum during pre-monsoon followed by winter and then monsoon (Chakravarti et al. 2004; Giri et al., 2005; Giri and Chakraborty, 2012; Dey et al. 2006).

2.22.4 Diversity of Zooplankton and Their Ecology in River Ecosystem

In any natural water body, zooplankton being an important biodiversity component forms linkages among different food chains and contributes considerably to enhance the biological productivity of system. In the study of the freshwater plankton, it is generally conceded that the Rotifera being the tiniest metazoan soft-bodied invertebrates shares the maximum proportion (Hutchinson 1967). Phylum Rotifera is represented by nearly **2500** species belonging to **120** genera and **30** families. However, only **330** species spread over to **63** genera, and **25** families have so far been documented from India of which **148** species belonging to **40** genera and **20** families were recorded from West Bengal (Sharma 1998).

In a freshwater system, the zooplankton forms an important faunal group, as most of them live on primary producers and make themselves available to be eaten by faunal components representing higher trophic levels including fish and thereby boosting up the biological productivity of this ecosystem. The abundance of zooplankton has been found to be most distinct in the slower-moving portion of a river system. However, deeper water having reduced velocity of water current coupled with silt deposition makes them indistinguishable from typical lentic habitats (Winner, 1975). Both the diversity and biomass of the zooplankton of perennially lotic water bodies (rivers and streams) always remain in the minimum level (Winer, 1975). In the zooplankton community of stable river system, the dominant members are the ploimate rotifers and the microcrustacean like Cladocera and Copepoda, while euplanktonic rotifers represent the major component of zooplankton community of most river systems (Winner, 1975). Such rotiferan communities show considerable variation in density as well as in diversity in different types of streams.

Zooplankton being the smallest group of aquatic metazoan display spatial heterogeneity, and the study of this group is very much convoluted because of changing space and time having environmental, physical, geographical, and chemical differences involving ecological, extrinsic, and essential aspects. Among freshwater communities of particular importance, zooplankton have appeared to play determining roles in respect of ecosystem functioning This unique pelagic biotic component of rivers includes diversified taxonomic groups having varied forms of morphological excellences and reproductive and feeding strategies (Pennak, 1957) and acts as a link among different compartments of aquatic food webs through trophic interactions (Neves et al. 2003).

The structure of zooplankton communities depends on a complex interaction of different morphometric and regional climatic factors, which in turn govern important physical and chemical characteristic of water bodies, edaphic features, and vegetation cover (Margalef, 1983); biogeographical factors which in turn determine species colonization (Dumont and Segers 1996; Rocha et al. 1999); and several biotic interactions, mostly centered on competition for food and prey (Gliwicz and Pijanowska, 1989; Dumont et al. 1994). The typical zooplankton assemblage of freshwater aquatic ecosystem is commonly comprised of Rotifera, Cladocera and Copepoda (Batish, 1992; Sharma 1998; Rocha et al. 1999; Reddy, 2001; Pradhan and Chakraborty 2006; Pradhan et al. 2006, 2008). As the key trophic group in aquatic ecosystem, zooplankton links up primary producers and fishes.

Research findings on zooplankton ecology generate baseline information which are being utilized to develop technology of water resource management, viz., water quality biomonitoring, aquaculture management, etc. Zooplankton of tropical freshwater often accommodates oriental/Palearctic species in addition to tropical one, leading to high diversity (Sharma and Sharma, 2008).

However, anthropogenic activities, such as urbanization coupled with industrialization, and different types of aquatic pollution especially eutrophication affect habitats of zooplankton causing biodiversity loss. The limnetic zooplankton representing different aquatic habitats resemble closely each other, and all the eutrophic species have been found to occur in the different types of freshwater habitats, like ponds, large plain wetlands, slow-moving rivers, etc.

The zooplankton of a river contribute significantly to the biological productivity of this ecosystem (Winner, 1975). The abundance of zooplankton, forming an integral part of the lotic community especially mostly in the slower-moving portions of a river system where deeper water tends to reduce current velocity and silt deposition in order to make this ecozone indistinguishable from typical lentic habitats (Winner, 1975).

2.22.4.1 Diversity of Rotiferan Zooplankton

Rotifera, one of the oldest groups and a minor phylum of invertebrates, are commonly termed as **wheel animalcules** because of their characteristic **wheel organ** or **corona** that bears close resemblance to a pair of revolving wheels. Although the rotifers represent a very small group (minor phyla) of animal kingdom, they are often considered qualitatively and quantitatively the most abundant metazoans in inland water (Sharma 2001).

Rotifers, the most important soft-bodied invertebrates (Hutchinson 1967), are an important food source for aquatic invertebrates and fishes and form the second step of the food chain, presenting a high diversity in freshwater ecosystems (Serafim et al. 2003). Early studies on rotifer distribution have established that almost all rotifers are cosmopolitan, but recent findings have pointed out the occurrence of endemism in several rotiferan genera (Nogrady, 1993). In general, planktonic rotifers dominate the zooplankton community of most river systems (Winner, 1975).

Rotifers, being the smallest form of pelagic metazoan and representing the most abundant group of freshwater zooplankton, play an important role as an integral link in aquatic food chain accelerating and enhancing the secondary production in freshwater ecosystem. These pseudocoelomate, microscopic, planktonic faunal components (size ranging between **40 μm and 250 μm**) possess unique form of morphology (ciliary crown, mastax, etc.) and adaptability (cyclomorphosis, alternative modes of reproduction (sexual and parthenogenetic)).

The rotifers have been recognized as significant indicators of trophic status of their environs. These smallest aquatic metazoans also exhibit remarkable ability to colonize diversified freshwater ecosystems and depict interesting reproductive and population dynamics. Certain taxa display ecotypic and cyclomorphic variations (Sladecek 1983).

Many studies have been made on the ability of certain groups of closely related species to coexist in the same area while utilizing the same pool of resources. The rotatorian fauna of freshwater zooplankton in which most of the species feed by concentrating small particulate matters with currents generated by their coronal cilia is a good example of the puzzling simultaneous occurrence of related species (Miracle, 1974).

Different families of rotifers are endowed with their own specialized types of mastax in tune with different types of feeding behaviors. However, there are many examples of coexistence of different species of rotifers belonging to the same genus is possible because of having same types of mastax. The rotifers may also compete with other zooplanktonic species including calanoids and cladocerans which can feed on particles down to **1–15 μm**.

Phylum Rotifera is represented by nearly **2500** species belonging to **120** genera and **30** families. Referring to the status of the Indian Rotifer, only **330** species spread over to **63** genera and **25** families have so far been documented (Sharma 1998), and the overall diversity of rotifer in the state of West Bengal, India, is **148** species belonging to **40** genera and **20** families (Sharma 1998).

Rotifers have been classified into the subclass Eurotatoria by Bartos (1959) which is further subdivided into superorders, i.e., Monogononta and Digononta. Mongononta includes orders Ploimida and Gnesiotrocha. There are **12** families and **135** species under Ploimida and **5** families and **11** species under Gnesiotrocha. Superorder Digononta includes order Bdelloidea with only 1 family and 1 species (Sharma 1998).

A comprehensive taxonomic survey on the diversity of rotifers from the freshwater ecosystems of West Bengal have revealed that different families under the phylum Rotifera embody **37** species of Brachionidae, **6** species of Euchlanidae, **4** species of Mytilinidae, **3** species of Trichotridae, **19** species of Collurellidae, **46** species of Lecanidae, **6** species of Notommatidae, **6** species of Trichocercidae, **2** species of Asplanchnidae, **1** species of Synchaetidae, **2** species of Dicranophoridae, **3** species of Gastropodidae under order Ploimida; **2** species of Conochilidae, **1** species of Hexarthridae, 3 species of Testudinellidae, **4** species of Filinidae, **1** species of Trochosphaeridae under order Gnesiotrocha, and **1** species of Philodinidae under order Bdelloidea (Sharma 1998). The rotifer taxa so far known from West Bengal which comprised **49.3%** of Indian rotiferan species and about 30% of the species under the phylum Rotifera are from the Oriental region.

The monogonots constituted a major component of taxa documented from the state of West Bengal, India, significant fraction of which was contributed by the members of the families Lecanidae, Brachionidae, and Colurellidae. The predominance of several species under the genus of *Lecane* and *Brachionus* has shown broadly tropical characters to the rotifer fauna of West Bengal, India, which have included a notable number of biogeographically interesting elements. Of these, *Brachionus donneri, B. bidentita jirovci, B. patulus macracanthus, B. sessilis, Mytilina acanthophora, M. ventralis longidactyla, Lecane bifastigata, L. pertica, L. hastate, L. curvicornis nitida, L. ligona, L. stokesii, L. (Hemimonostyla) syngenes, L. (Monostyla) thalera, L. (M.) sinuate, L. (M.) thienemanni, Trichocerca elongate braziliensis, Dicranophorus lutkeni, Collotheca tenuilobata, and Horaella brehmi* reflected global distributional significance, while a number of other documented species indicated regional distributional importance within India or in the Indian subcontinent.

In addition, various pantropical, tropical, and subtropical elements were also well represented in the samples from West Bengal, India (Sharma 1998). Pradhan et al., 2003, 2006; Pradhan and Chakraborty, 2006, 2008 conducted a study on nine different sites along three different freshwater rivers, viz., Dwarkeswar, Shilabati, and Kansai. Forty six species belonging to **2** orders, **11** families, and **15** genera under the phylum Rotifera were recorded. Halder et al. (2007) conducted a survey of zooplankton from **7** wetlands in the districts of Midnapore (East and West) and Purulia of the state of West Bengal, India, and found that rotifers comprised **28** species under **12** genera and **10** families, namely, Brachionidae, Lecanidae, Notommatidae, Trichoceridae, Asplanchnidae, Synchaetidae, Euchalanidae, Colurellidae, Filinidae, and Philodinidae. Datta (2011) from his study on **2** wetlands of Jalpaiguri district, West Bengal, recorded that rotifers were the most abundant zooplankton with **48** species among which **11** belongs to the genus *Brachionus*, followed by **9** species under the genus *Lecane*.

2.22.4.2 Diversity, Distribution, and Seasonal Fluctuation of Rotiferan Zooplankton in Shilabati River, West Bengal, India

In a zooplankton community of a stable river system, the dominant members are the Rotifera, Cladocera, copepod, Ostracoda, Protozoa and certain insect larvae. Among these, in general, euplanktonic rotifers dominate the zooplankton community of most river system, which perform significantly in maintaining aquatic food chain and constituting a novel source of food for fishes. Rotifera, the microscopic fungal component living mostly in freshwater, are characterized by the presence of an anterior wheel-like rotating structure called "**corona**." Besides, as a bioindicator species, zooplanktonic Rotifera has made an inroad in the biomonitoring of ecological changes in river ecosystem (Pradhan et al. 2003; Sanyal et al., 2015).

A recent long-term ecological study undertaken to investigate the zooplanktonic rotiferan diversity in the freshwater river, namely, in the Shilabati River of South West, Bengal, India, through different months and seasons during the period of July 2001 to June 2003 has revealed the occurrence of **31** species of rotifer belonging to **12** genera, **9** families, and **2** orders which have been recorded during this study period in this river which comprises about **21%** of the known species (**148**) of West Bengal (Sharma 1992) and **10%** of the known species (**330**) of Indian Rotifera (Sharma 1998). Although all these species had earlier been reported from some other districts of West Bengal, they are reported for the first time from this river, and out of **31** species, **22** species are reported first time from the erstwhile undivided Medinipur district of West Bengal, India.

Out of these **9** families, the rotiferan family Brachionidae include highest number of species (**12**) followed by Lecanidae (**9**), Trichocercidae (**2**), Euchlanidae (**2**), and Filinidae (**2**), and other families like Aaplanchnidae, Synchaetidae, Trichotridae, and Colurellidae were represented by **1** species each. Among these two zones, zone I and zone II harbored **28** and **26** species of Rotifer.

The present study also revealed that during pre-monsoon season, the diversity and density of rotifer reached its peak followed by postmonsoon and monsoon. Sharma et al. in 1999, reported that, in Tungabhadra River of Karnataka, there was a complete absence of rotifers in monsoon in the entire stretch of the river water. In the Ganga River, Sinha (1992) also recorded total absence of rotifers in the monsoon season.

But the present study showed the presence of this group of zooplankton in all sampling zones of the studied rivers through different months and season of year, although population density drastically reduced during monsoon. The present study also highlighted that there was a significant negative correlation of water current with the density of Rotifera in all rivers **(Table 2.8)**.

2.22.4.3 Ecological Gradients Determining the Distribution of Rotiferan Zooplankton in a Tropical Freshwater River

Shilabati River, a well-known freshwater river of South West Bengal, India, after originating from Baragram (**23 ° 15’N** and **86 ° 39′E**) on the Manbazar, block of Purulia district of West Bengal, India, flows through the district of Midnapore (West) district, West Bengal, India, and meets with the Dwarkeswar River at Bandar on the border of the Hooghly district, West Bengal, India, with Midnapore (West) district, West Bengal, India, and ultimately opens to the Rupnarayan River.

Two sampling zones were selected on this river – first one on the upper stream at Garbeta subdivision (**22 ° 54’ N-22^{0} 52’ N; 87 ° 12′E-87^{0} 49′E**) and second one on the downstream at Ghatal subdivision (**22 ° 40’ N-22^{0} 42’ N; 87 ° 40′E-87 ° 49′ E**). A total of **31** species of rotifers belonging to **12** genera, **9** families, and **2** orders have been recorded during this period in this river which comprised **20.9%** of the known species (**148**) of West Bengal (Sharma 1992) and **9.4%** of the known species (**330**) of Indian rotifer (Sharma 1998).

Out of these **9** families, Brachionidae included highest number of species (**12**) followed by Lecanidae (**9**), Filinidae (**2**), Euchlanidae (**2**), and Trichocercidae (**2**), while families like Asplanchnidae, Colurellidae, Trichotridae, and Synchaetidae are represented by **1** species each. But the present study showed that this group of zooplankton was present in both the studied zones of this river through different months and seasons of **2** consecutive years, while the abundance was drastically reduced during monsoon because of the differential influence of several ecological parameters.

Hofmann (1977) opined that not only does temperature exert a significant influence on population dynamics by its direct influence on embryo on the development but also it governs the enzymatic activities of any living organism. In the present study, temperature ranged from **16 °C to 35 ° C** in zone **I** and **17 ° C to 33 ° C** in zone **II** which was neither extreme cold nor excess hot, and that is why temperature was supposed to have played little impact on rotifer population. The correlation between rotifer and temperature showed positive relationship (**0.341** and **0.300**, respectively, for zone I and zone II of this river).

It has been found that the rotiferan species with well-developed lorica such as *Brachionus and Keratella* displayed higher population density during the period when the alkalinity was high (Dhanapathi 2000), but in the present observation, the water condition was neither acidic nor alkaline where both the genus *Brachionus* and *Keratella* inhabited. Sharma (1992) also recorded various acidophilic species such as *Keratella cochlearis* and *Brachionus patulus* from different freshwater bodies of West Bengal. In contrast, *B. bidentata*, *B. rubens*, *and Lecane lunaris* were regarded as basophilic fauna because of their preference to inhabit alkaline water. But in this study, as a whole rotifer community always showed significant positive correlation with alkalinity (**0.686** for zone I and **0.599** for zone II, respectively (Pradhan et al. 2003; 2008, Prodhan and Chakraborty, 2006, Giri et al. 2008).

Hofman (1977) stated that although **pH** varies in space and time, little is known about its influence on population dynamics of rotifers. Regarding the effect of **pH**, Pennak (1978) opined that alkaline waters with a **pH** above **7.0** contain few species with larger number of individuals, while acidic water contains large number of species but with few individuals. In this study, although it was found that **pH** values always ranged between **6.1** and **7.9** (both in zone **I** and zone **II**), and thus in most cases, it remained to both acidic or alkaline range rotifer showed significant positive correlation (**0.628** and **0.732** for zone **I** and zone **II**, respectively) with **pH**. Dissolved oxygen (**DO**) plays an important role in determining the occurrence and abundance of rotifer communities (Dhanapathi 2000). Hofman (1997) observed oxygen concentration as to be an important factor in determining seasonal, horizontal, and vertical variations of rotifers, while Berzins and Pejler (1989b) noticed wider range of oxygen is required for the occurrence of these organisms. In this study, an inverse relationship (**r = −0.509** and **– 0.325** for zone **I** and zone **II**, respectively, of Shilabati River) was noticed between rotifer abundance and dissolved oxygen which was supposed to be due to the respiratory activity of the rotifers and other zooplankton and also because of utilization of oxygen for decomposition of algal bloom at higher temperature.

Species that occur and prefer water with high **DO** values such as the genus *Lecane* and *Asplanchna* (Dhanapathi 2000) are recorded in high **DO**. Pejler (1957) and Pourriot (1965) pointed out that cold stenothermal forms are more tolerant of low oxygen content in the water than eurythermal species. In this study, **DO** exhibited negative correlation with Rotifera in most cases. **Chemical oxygen demand (COD)** always displayed significant positive correlation with rotifer density in general (**r = 0.678** and **0.821** for zone **I** and zone **II**, respectively). **Biological oxygen demand** (**BOD**) also revealed positive correlation with rotifer density (**0.302** and **0.232** for zone **I** and zone **II**, respectively). Total hardness registered a significant relationship (**r = 0.515** and **0.493** for zone **I** and zone **II**, respectively) with rotifer abundance in Shilabati River. Conductivity and total dissolved solid also exhibited positive correlation with rotifer density (**r = 0.281** and **0.344** for zone **I** and **0.748** and **0.747** for zone **II**), but total suspended solid showed significant negative correlation with rotifer density (**r = −0.747** for zone **I** and **− 0.428** for zone **II**) **(**Pradhan et al. 2003, 2006, 2008, Pradhan and Chakraborty 2006, Giri et al. 2008)**.**

Total Kjeldahl nitrogen and total phosphate phosphorus displayed no definite relationship with rotiferan population. Zooplankton and the rotifer population in the river system are affected by a number of environmental factors (Greenberg 1964; Hynes 1970). The most important changes in the plankton populations occur as a function of time of the year and downstream water movement.

The zooplankton productivity of a river is proportional to the age of its water and inversely proportional to its velocity (Reinhard, 1931; Eddy, 1994). In this study, the rotiferan population registered a highly significant inverse relationship with water velocity. For rotifer, these were **−0.858** and – **0.544** for zone **I** and zone **II** of Shilabati River, respectively, which was in tune with the findings of Reinhard (1931) and Eddy (1934).

Stepwise multiple regression analysis also revealed that the species abundance and density of rotifer population were significantly influenced by seven important water parameters, viz., water velocity (**WC**), **pH**, alkalinity, total hardness, chemical oxygen demand (**COD**), biological oxygen demand (**BOD**), and total Kjeldahl nitrogen (**Table 2.6**).

In the study, a positive relationship in between rotifer density and **pH**, alkalinity, **COD**, and total Kjeldahl nitrogen and a negative relationship in between water velocity, total hardness, and **BOD** have been observed. Similar relationships have been recorded by most of the researchers in the case of water velocity, pH alkalinity, and **COD** (Reinhard, 1931; Eddy, 1934; Edmondson 1959; Micheal, 1968; Pejler 1957; Dumont, 1983).

Two-way **ANOVA** analysis revealed that rotifer community displayed significant variation over different months (**F = 21.39, F crit = 1.59**) but not over space (**F = 1.52, F crit = 2.28**). It has also been found that the survivability of the rotifers belonging to different families are being determined by different set of ecological parameters, viz., most of the species of family Brachionidae (*Brachionus calyciflorus*, *Keratella tropica*, *Keratella cochlearis*) was found to have been more independent on **DO**, but species with well-developed lorica such as different species under the genus *Brachionus* and *Keratella* built higher population during the period when the alkalinity was high (Dhanapathi 2000). The rotifers belonging to families Lecanidae and Asplanchnidae are found to prefer waters with high **DO** values. On the other hand, species of families Filinidae and Brachionidae (*Platyias quadricornis*) were mostly found at low oxygen concentration. However, the environment of lotic water body is governed by an array of so many parameters like meteorological, physicochemical, and biological parameters (Pradhan et al. 2003, 2006, 2008, Pradhan and Chakraborty 2006, Giri et al. 2008).

2.22.4.4 Diversity, Distribution, and Seasonal Fluctuation of Rotiferan Zooplankton in Kansai River

A study undertaken to investigate the rotiferan diversity in relation to different water quality parameters of Kansai River (originating as Kansai Nala from Jabarban hill peak on the Ghoramara hill of Purulia district, West Bengal, India) has revealed the presence of **26** species of Rotifera belonging to **9** genera, **7** families, and **2** orders which have been recorded during this study period from this river which comprised **18%** of the known species (**148**) of West Bengal (Sharma 1992) and 8% of the known species (**330**) of Indian Rotifera (Sharma 1998).

Out of these **7** families, Brachionidae consisted of the highest number of species (**11**) followed by Lecanidae (**9**) and Filinidae (**2**), while families like Euchlanidae, Asplanchnidae, Synchaetidae, and Testudinellidae were represented by **1** species each (**Table 2.8**). Zone I harbored 2**1** species and zone **II** harbored **23** species of Rotifera.

The study also revealed that during pre-monsoon season, the diversity and density of Rotifera reached its peak followed by postmonsoon and monsoon (**Table 2.8**). Total absence of rotifers was reported in the entire stretch of Tungabhadra River of

Karnataka which received domestic sewage during monsoon (Sharma et al. 1999). In the Ganga River, Sinha (1992) also reported the complete absence of rotifers during monsoon.

However, this group of zooplankton was present in both the zones studied through different months and seasons of 2 consecutive years though the abundance was drastically reduced during monsoon. Physicochemical parameters of water displayed different characteristics among two zones of this river. It was also found that there existed no significant relationships between temperature and rotifer abundance which corroborates the observation of Berzines and Pejler (1989). But as most of the members of the family Brachionidae, Lecannidae, Euchlanidae, Synchaetidae, and Testudinellidae are warm stenothermal and basophilic in nature, they were eventually found during pre-monsoon season. On the other hand, members of family Asplanchnidae and Filinidae were mostly recorded during postmonsoon season as they were cold stenothermal and acidophilic in nature.

This study also corroborates the findings of Michael (1968) and Nayar (1970) with regard to the coincidence of rotifer abundance with alkalinity, but this parameter did not show significant relationships with rotifer density in all situations. In general Rotifera showed significant positive correlation with alkalinity. The dissolved oxygen did not show significant relationship with rotifer abundance because most of the species were either independent of **DO**., e.g., *Keratella tropica, Keratella cochlearis* are able to survive in low oxygen concentration, e.g., *Platypus quadricornis* or able to survive in high oxygen concentration, e.g., *Asplanchna priodonta* (Dhanapathi, 2000) but in general total rotiferan population showed significant negative correlation with oxygen for zone II). Regarding other physicochemical parameters, there existed no significant relationships with rotifer abundance. Different researchers from different parts of world showed that Rotifera as a phylum did not follow definite relationships with major water quality parameters (Dhanapathi 2000; Sharma 2001; Sladecek 1995). The same study also highlighted that there was a significant negative correlation of water current with Rotifera abundance in both the study sites (Pradhan and Chakraborty 2006; Pradhan et al. 2003, 2006, 2008)

2.22.4.5 Diversity of Zooplanktonic Cladocera and Copepoda

2.22.4.5.1 Diversity and Distribution of Cladocera in the River System

Among the freshwater zooplankton, next to the Rotifera, faunal components under the order Cladocera constitute the second largest group of zooplankton and are commonly termed as "**water fleas**" because of their characteristic **jerky** swimming action during locomotion (Brooks, 1959).

The Cladocera are important components of microfaunal food web and constitute an integral link in any aquatic food chain. They exhibit wide variety of feeding habits and are generally herbivores, bacterivores, or detritivores, scrapping epiphytic algae or else feeding on bacteria and detritus found in macrophytes, sediments, and other substrates. They also serve as a major food items for many invertebrates and vertebrates (Reddy, 2001).

They invariably comprise food for fry, fingerlings and adults of various economically important cultivable species of fishes. The littoral and limnetic cladoceran contribute significantly to biological productivity and energy flow in freshwater environments because of their rapid turnover rates, metabolism, and adaptability to build up substantial population within short time intervals.

Sharma (2000) established the role of Cladocera as an indicator species. Blanco et al. (2011) also established that cladocerans remain a powerful tool to detect ecological changes and eutrophication. Sharma (1978) documented **24** species of Cladocera especially from South **24** Parganas district, West Bengal, India, and in the vicinity of Kolkata city of West Bengal, India.

Out of those new records, several temperate species have been encountered from the floodplain regions of the West Bengal, viz., *Diaphanosoma brachyurum, Daphnia similis, Grimaldina brazzai, Chydorus pubescens, Chydorus faviformis, Leydigia acanthocercoides, Graptoleberis testudinaria, Alona intermedia, Alona costata, Alona rectangular*, and *Camptocercus australis*. Halder et al. (2007) conducted ecological and taxonomic surveys of zooplankton from seven wetlands in Midnapore and Purulia districts of West Bengal, India, and recorded nine (9) species of Cladocera (**Tables 2.8 and 2.9**; **Figs. 2.2 and 2.3**).

2.22.4.5.2 Diversity and Distribution of Zooplanktonic Copepod in the River System

Copepoda, an important group of zooplankton, is a very ancient arthropod and the diminutive relative of crabs and shrimps (Reddy, 2001). As to their functional significance, copepods are significant primary and secondary consumers in aquatic food chains. Their grazing feeding habits contribute to the transfer of algal primary production to higher trophic levels. Copepods are being used as suitable faunal components in monitoring studies in the field and also in the laboratory.

The calanoid/cyclopoid-cladoceran ratio has been used in limnological studies as a water quality indicator, the high value of which indicates the oligotrophic conditions and low values indicate the hypertrophic condition (Reddy, 2001). Bhunia et al. (2008) recorded the occurrence of four copepodan species (Family: Diaptomidae: **1)** *Heliodiaptomus viduus*; Family Cyclopidae: **2)** Eucyclops sp; **3)** Mesocyclops sp.; **4)** *Microcyclops varicans*) and Nauplius larvae of copepods from small-sized perennial water bodies, locally named as ponds of Midnapore district, West Bengal, India. Ganesan and Khan's study (2008) has revealed the occurrence of seven species of copepodan zooplankton from the oxbow lake of West Bengal, India.

2.22.4.6 Zooplanktonic Copepoda–Microbes Interactions: A New Vista in Establishing the Connection of Epidemiology with Zooplankton Ecology

A recent study on the zooplankton–microbes interactions have unearthed some valuable information of the antimicrobial susceptibility of several bacterial strains inhabiting the appendages of the body of a zooplanktonic copepod (*Heliodiaptomus viduus*, Gurney, 1916) inhabiting both fresh and brackish water bodies of Midnapore (West and East) districts, West Bengal, India (Midya et al. 2019).

Out of **62** bacterial isolated strains, **38** isolates were identified as Gram-positive, while the remaining **24** isolates were found to be Gram-negative. Antimicrobial properties of all the isolated bacterial strains had exhibited different types of susceptibilities against different selected antibiotics. The research findings of the study have opened up new vistas to the health professionals in identifying two major aspects out of zooplankton–microbes interactions:

1) Functional association of bacteria with zooplankton (**Fig. 2.4**), a major biotic component of aquatic food webs for the mutual benefits of two. The zooplankton has so far been recognized as the novel source of life food for fish in the aquatic ecosystem and also play important roles as bioindicators (Pradhan et al. 2003), but no such information have been there on the roles of zooplankton in transmitting pathogenic microbes to the human body through the natural surface water where they provide the bacteria shelter.

2) Selection of antibiotics to combat the problems derived from the pathogenic effects of zooplankton-associated bacteria on human being.

Despite complete niche differentiation different species zooplankton and strains bacteria in the aquatic ecosystem, both of these aquatic biota experience mutual interactions and help maintaining the ecodynamics of the aquatic ecosystem (De Souza Cardoso et al. 2019). The bacterial population in an aquatic ecosystem either as plankton or as biofilm has been seen to be associated with the external body parts of zooplankton (Lawrene et al. 1987). Bacteria are supposed to derive benefits out of such interactions in the form of shelter and protection and also by harvesting organic carbon as nutrients from the chitinous appendages of copepods (Verschuere et al. 2000a, b). The enrichment of chitinous body covering of zooplankton with reactive dissolved organic carbon (**DOC**), an attractant of waterborne bacteria, is thought to be due to the continuous supply of both autochthonous and allochthonous nutrients in the aquatic habitats of zooplankton and their sloppy feeding habits (Peduzzi and Herndl, 1992; Hansson and Norrman 1995, Moller 2005; Berggren et al. 2015). The occurrences of several bacteria, viz., *Enterobacter cloacae* complex (**SR1**), *Klebsiella pneumoniae* (**SR2**), *Enterobacter aerogenes* (**SR3**), *Aeromonas sobria* (**SR4**), and *Pseudomonas aeruginosa* (**SR5**) as Gram-negative and *Staphylococcus pseudintermedius* (**RS1**) and *Staphylococcus aureus* (**RS2**) as Gram-positive bacteria isolates (Middya et al. 2019). These bacterial species by virtue of their wide range of tolerance against ecological odds not only ensure their survivability but also cause several health problems to human being after being transmitted by their host zooplanktonic species (Kobyashi et al. 2015). These bacteria do not only erode the soft tissues of human beings but cause severe syndrome by invading beneath the skin of human beings and thereby spread the bacterial infection. It has also been noted from this study (Midya et al. 2019) that these bacterial species develop resistance to ß-lactam antibiotics and thereby pose problems to the health professionals. Outbreaks of pathogenicity due to the interspecies interactions and relationships cause disturbation of environmental health of ecosystem, especially the aquatic ones which have become an emerging phenomenon of global concern. Besides, such outbreaks have become aggravated by developing resistant bacterial isolates over multiple antibiotics (Kobayashi et al. 2015). In the study conducted by Midya et al. (2019), out of **14** tested antibiotics, amoxicillin or clavulanic acid (penicillin group) displayed resistivity to all the Gram-negative isolates, whereas antibiotics under the cephalosporin group especially cefuroxime exhibited resistivity for *Enterobacter cloacae* complex, *Enterobacter aerogenes*, and *Aeromonas sobria*. The bacterial species *Pseudomonas aeruginosa* also revealed resistivity to all the antibiotics (cephalosporins and sulfamethoxazole) with high **minimum inhibitory concentration** (**MIC)** values (Midya et al. 2019).

Besides, based on the findings of this research study (Midya et al. 2019), the following hypotheses have been proposed:

1. In both freshwater and brackish water ecosystems, zooplankton and bacteria, being two major biotic components, displaying mutualistic relationship and utilizing ecological niche partitioning, exhibit their functional roles independently of each other after being supported by the prevailing ecological factors.
2. Zooplankton–bacterial association experiences variability in changing ecological conditions at different periods and ecozones.
3. Underlying ecological principles triggering the interlinkages and interrelationships in between bacteria and zooplankton are governed not only by nutrient flow among the different aquatic trophic levels but also by the ability of chitinolytic bacteria (*Aeromonas* spp.) to invade the body of zooplankton, the copepod: *Heliodiaptomus viduus*. in the present study (Midya et al. 2019).
4. The bacterial strains both Gram-positive and Gram-negative isolated from the body parts of zooplankton exhibited variable susceptibilities against selected antibiotics and antibacterial activities.

Moreover, the research outcomes of this study depicting zooplankton–bacterial interactions can be treated as an integrated approach towards developing knowledge on the mode of mutual interaction of two distinctly separated organisms. Bacterial characterization over these two aspects will definitely create a new vision in the context of health challenge and ecosystem safety.

2.22.4.7 Functional Roles of Zooplankton

As the trophic component and bioindicator, zooplankton plays critical roles as bioconverter in converting plant food to animal food and also as a source of food for higher organisms including fishes (Korstad, 1983). In addition, morphometry of the water body, temperature, pH, alkalinity, dissolved oxygen, hardness, abundance of food, and organic matter are other factors that influence the incidence of abundance and diversity of zooplankton and thereby require a careful evaluation of various relationships between zooplankton population and other factors (Hazelwood and Parker, 1961; Battish, 1992).

The main groups composing zooplankton communities of these rivers and their adjoining water bodies are the Rotifera, Cladocera, and Copepoda, although freshwater river zooplankton, especially in tropical regions, may contain a diverse set of taxonomical categories (Wetzel 2001; Dumont et al. 1994). The intensity of aquatic pollution can be judged from occurrence, abundance, and species composition of the biotic community.

The use of indicator organisms in the assessment of water quality depends upon a thorough knowledge of the ecological tolerance of the organisms concerned. A biological indicator is meant to give a useful biological measure that is sensitive enough and can be used for diagnosis, control, prevention, and reclamation (Ghetti and Ravera, 1994). Rotifera, one of the major groups of zooplankton, comprise an important component of lotic as well as lentic invertebrate communities in freshwater environment.

They have attracted attention of several workers globally, with reference to their significance as bioindicators of water quality, trophic status, and environmental toxicity studies. Rotifera are good indicators of saprobity also. This study had recorded **47** species of Rotifera, **12** species of Cladocera, and **6** species of Copepoda from the studied river ecosystem (**Tables 2.8 and 2.9)**

2.22.4.8 Mollusks: Diversity and Functional Roles

The mollusks in the riverine ecosystem are mainly represented by gastropods and bivalves (**Tables 2.10 and 2.11**). The gastropods feed primarily on organic matters (mostly decaying weeds and occasionally some dead animals) that constantly accumulate at the bottom of the water bodies. A total of **23** species of mollusks belong to **16** genera of all recorded species, **9** species were found to inhabit freshwater habitats, **14** species preferred to reside in saline environment, while 4 species were encountered both in freshwater and brackish water zones (Pakhira and Chakraborty 2016, 2018).

Bivalves, on the other hand, are generally filter feeders, harvesting and scavenging dead organic remnants from the overlying water and mostly prefer to inhabit macrophytes dominated benthic zones and need macrophyte as the main substrate for their movement (Hershey and Lamberti, 2001). Phillips (1980) investigated the metal accumulation ability of bivalve *Lamellidens marginalis*. Besides, bivalve mollusks have been extensively used to monitor trace elements in marine and estuarine environments as bioindicator species (Phillips, 1980; Ritz et al. 1982).

The higher abundance of mollusks indicates the unproductive character of the aquatic ecosystem (Sinha, 2000). It also suggests the possibility of the waters to become more alkaline. Higher production of mollusks tends to increase the calcium content of the habitat, and when the precipitation of calcium is on the rise, the alkalinity goes high leading to a state undesirable for a number of phytoplankton because the phenomenon of calcifobis starts operating (Sinha, 2000).

2.22.4.9 Oligochetes as Important Soil Inhabitant Faunal Components

A number (**17** species) of soft-bodied oligochaete fauna have been recorded (**Table 2.13**) from the different rivers and streams of South West Bengal, especially in moistured enrich sediments of West Midnapore district, West Bengal, India (Chandra et al. 2003). These faunal components not only contribute functional roles in the food chain–food web dynamics of the water-terrestrial fringes, but also by virtue of their unique body movements in the soil, they act as important bioturbators, reshuffling the textural components as well as the nutrient profiles of the soils.

2.22.4.10 Aquatic Insects: Diversity and Functional Roles

Aquatic insects are more prevalent in shallow water mainly because of their partial adaptation to the aquatic life. Several species of aquatic insects mainly belonging to the orders Coleoptera, Hemiptera, Dermaptera, and Odonata are found to occur in the different freshwater riverine networks of South West Bengal, India (Anon, 2014) (**Table 2.12; Fig. 2.7**). There are seven or eight groups of insects which depend heavily on macrophytes for their food and breeding activities. Some of them feed directly on the plant materials (Coleoptera, Lepidoptera), while others graze on it. Some species lay their eggs inside the tissue of the plants (Hemiptera), while others use plants as a substrate for breeding purposes. Some other species used to construct small nest-like structures for rearing their larvae with the help of small pieces of twigs and leaves (Lepidoptera).

2.22.4.11 Diversity of Crustaceans

Crustaceans, a major higher taxa under the phylum Arthropoda, are mostly represented by several ecologically and economically important faunal groups such as shrimps, prawns, lobsters, crabs, and barnacles and an array of microscopic species such as Cladocera, Copepoda, etc. They are characterized in having a protective chitinous or subcalcareous "**crust**" or cover which is cast off periodically. Out of a good number of crustacean inhabitants in the freshwater rivers, **11** species have been recorded from the freshwater rivers of South West Bengal, India (**Table 2.14**). So many microcrustaceans such as Cladocera and Copepoda along with different species of small prawns serve as novel source of food of fishes and other larger aquatic animals. The basic body plan crustacea although follow the arthropodan body plans with **20** segments which are reorganized as anterior cephalothorax (amalgamation of the segments of head and thorax) forming and posterior elongated abdomen composed of six movable segments occasionally terminating with terminal telson as in crayfish, lobster, etc. Behind the cephalothorax is the flexible abdomen and the hindermost telson.

Each segment bears a pair of biramous appendages, i.e., with a basal part and two branches arising therefrom. In the adult, however, the appendages get greatly modified to perform different functions. The **13** segments of the cephalothorax bear the following appendages:

First – a pair of many-jointed, filamentous antennules for feeling and keeping the equilibrium of the body

Second – a pair of long many-jointed antennae for feeling

Third – a pair of jaws or mandibles for crushing the food

Fourth and **fifth** – each a pair of maxillae for creating currents of water in the gill chamber

Sixth, seventh, and **eighth** – each a pair of food-jaws or maxillipeds for chasing and holding the food

Ninth to **thirteenth** – each a pair of walking legs for walking and feeling

Each of the abdominal segments (**14**th to**19**th) carries a pair of appendages to function as swimming organs or swimmerets. The pair of appendages on the **14th** segments are reduced in the female, but in the male, they function as organs for transferring sperms. The appendages on the **15th** in the male are used for transferring sperms and in the female for attachment of the eggs. The appendages on the **16th**, **17th,** and **18th** segments are used for swimming and also in females for the attachment. The terminal segment designated as uropods is for directing the pathways during swimming.

2.22.4.12 Diversity of Freshwater Ichthyofauna

India being one the eighteenth megadiversity countries of the globe supports a galaxy of freshwater faunal resources which inhabit diversified water bodies such as rivers, streams, wetlands, lakes, etc., of which fishes inhabiting different ecosystems, habitats, and niches of aquatic environment represent most important one not only for their ecological roles but on the human dependence on this faunal group for economic development of the country. Besides, they are the chief source of protein not only for their diversity but also for their capability of continuous propagation vis-à-vis abundance in natural habitats, which have been drastically degraded during the last few decades due to rapid pace of urbanization coupled with industrialization.

The systematic and strategic eco-management of river system is the demand of the time to ensure conservation of ichthyofauna as most of them are under the threat of endangerment because of the construction of dams, channelization across the rivers, introduction of exotic species, releasing of sewages, and dumping of solid wastes from both the adjoining industries and municipalities to the rivers and streams affecting the upstream and downstream migration of migratory species.

Out of some scanty studies conducted to document the river ichtyofauna in India, a study on the rivers of the state of Karnataka, in South India, has generated a checklist of river fishes of the state Karnataka, India, which showed the records of **240** species (**109**, **59, 168** species of fishes from Cauvery, Godavari, Krishna, respectively, whereas **124** fish species were found to occur in the West flowing river basins) distributed under **102** genera, **38** families, and **14** orders. Among the most prevalent fish orders, Cypriniformes ranked first out of **140** species, **45** genera, and **5** families followed by Siluriformes (**51** species, **24** genera, and 9 families) and Perciformes (**26** species, **15** genera, and **9** families). Forty species are listed under threatened category including **5** species as critically endangered, **22** as endangered, and **13** as vulnerable.

Out of **103** species documented from different freshwater bodies of South West Bengal, India (lentic and lotic), **29** species were found to inhabit both fresh- and saline water bodies (Mishra et al. 2003). Chatterjee et al. (2000) reported **22** species out of these **29** species from Midnapore coastal belt. The occurrence of these fishes (**29**) in both freshwater and saline water was supposed to be due to their wide range of salinity tolerance.

Similar studies in other freshwater rivers and wetlands of other parts of India revealed the occurrence of **34** species belonging to **9** families and **5** orders from different freshwater bodies of Wayanad district, Kerala (Raghunathan, 1993); **18** species belonging to **2** families and **2** orders from Gori Ganga River, Uttarakhand (Joshi et al. 1993); **30** species belonging to **9** families and **6** orders from Kaveri River, Tamil Nadu (Madhyastha and Murugan, 1996); **32** species belonging to **12** families and **6** orders from the tributaries of Gadana River, Tamil Nadu (Arunachalam and Sankaranarayanan, 1999); **98** species belonging to **34** families and **10** orders from Chalakudy River system, Kerala (Ajithkumar et al. 1999); and **79** species belonging to **19** families and **6** orders from Damodar River, Bihar and West Bengal (Sarkar and Banerjee, 2000).

A comparison of a present study (Mishra et al. 2003) with those mentioned above clearly showed that the fishery potential of freshwater bodies of South West Bengal is still very commendable. As many stresses, viz., pollution due to rapid industrialization and urbanization, construction of barrages and dams, nonjudicious lifting of water from river bed for the purpose of irrigation and municipality, deforestation followed by soil erosion, overexploitation of ichthyofauna during breeding seasons, use of ichthyotoxic chemicals and plant extracts for fish harvesting, use of nylon thread net along with smaller mess sizes, etc. Causing degradation of fish environment are increasing, an immediate proper conservative strategy should be made for the protection of this valuable bioresource (Mishra et al. 2003).

2.22.5 *Biotic Community: Biodiversity and Conservation*

Since 1912, ecologists have been focusing not only on the occurrences but also the distribution of icthyotaxa which tend to vary in seemingly predictable ways from headwaters to mouth (Hawkes 1975). One of the common patterns is the peak in species richness in the longitudinal (length dimension) and middle courses of rivers, halfway between headwaters and mouth. Middle-course peaks was recorded to vary for most of the aquatic arthropods (Minshall et al. 1985; Naiman et al. 1987), mussels (Hughes and Parmalee 1999), and hydrophytes of rivers (Nilsson et al. 1989, 1991; Tabacchi et al. 1996). The peak in species richness in the middle courses of rivers reflects a general pattern, which is thought to be because of the influence of t environmental or biological variables (Vannote et al. 1980), disturbance regimes (Ward 1998), combinations of the two (Nilsson et al. 1989, 1991 Minshall et al. 1985, Naiman et al. 1987, al. 1996), or transitions of substrate related to glacial history (Nilsson et al. 1991).

2.22.5.1 Mid-domain Effect (MDE) and Environmental Correlates of Richness

A comprehensive study on the occurrences and distribution of natural plant species in Kalix and Torne Rivers, of Sweden, Europe, revealed that two biogeographically linked rivers were substantially influenced by the mid-domain effect in respect of richness patterns of riparian plants (Nilsson et al. 1989). Environmental factors are clearly important to the distribution of individual species along rivers, but their influence on longitudinal patterns of richness along rivers may often be modified or even dominated by **MDE.**

2.22.5.2 Shoreline as Ecological Habitat and Its Influence on Biodiversity

The shore zone of aquatic ecosystems facilitates interactions in between the terrestrial and aquatic ecosystems because of interlinkages which make it an ecologically more important, highly modified, and understudied habitat for the biodiversity to flourish enjoying higher heterogeneity and more supply of organic matter coupled with higher primary productivity, respiratory activities, and other biogeochemical processes in comparison to other zones within the river (Airoldi and Beck 2007; McLachlan and Brown 2006; National Research Council 2007; Strayer and Findlay 2010; Ward et al. 1999; Sabo et al. 2005; Kennedy and Turner 2011; Wetzel 1990; Polis and Hurd1996; Coupland et al. 2007; Strayer and Findlay 2010). However, human activities on shore zones for millennia such as agriculture, urbanization, commercial navigation, fishing activities, and ecotourisms have been the main center of attention resulting in considerable modification and alteration of this sensitive but productive ecozone (Tockner and Stanford 2002; Scholten et al. 2005; Strayer and Findlay 2010). Consequently, the biodiversity and ecological functions of many shore zones have been greatly reduced due to construction of many built structures such as walls and revetments designed to protect valuable waterfront property (Strayer and Findlay 2010; Kennedy and Turner 2011).

However, the biodiversity components of the shore zone have exhibited their dependence on the physical energy regime, geologic (or anthropogenic) structure, the hydrologic regime, nutrient inputs, and climate (Strayer and Findlay 2010). Strayer et al. (2012) have hypothesized based on their research on the Hudson River that high biodiversity would be associated with high physical complexity of shore zones, whereas engineered shore zones because of their simplicity in physical characteristics support lower biodiversity than natural shore zones.

It is imperative to restore and preserve a mix of shore types all along the gradient through which biotic communities consistently vary between wide, sheltered, fine-grained shore zones and narrow, exposed, coarse-grained shore zones, at least to the extent that they occurred naturally. In particular, narrow, exposed shore zones at a finer scale promote more diversity of organisms because of local roughness and heterogeneity (Barwick 2004; Brauns et al. 2007; Paetzold et al. 2008; Pollock et al. 1998;) and thereby destroying of such local heterogeneity by using uniform building materials, smooth may have strongly negative consequences for shore zone biodiversity, and should be avoided (Strayer and Findlay 2010).

2.22.6 Riverine Biodiversity

Asian freshwater ecosystems support an exceptionally rich biota, sharing highest global proportion of riverine biodiversity (Dudgeon 2000**)**. Indonesia in its different aquatic biotopes supports the lives of **900** amphibian species, at least **1200** fishes (the final total may exceed **1700** species), and more than **660** species of dragonflies (Bunn et al. 1997). The riverine networks of Asia represents the home of three species of **true** river dolphins out of the occurrence of five such across the globe, viz., *Platanista gangetica* (in the Ganges and Brahmaputra), *Platanista minor* (in the Indus only), and *Lipotes vexillifer* (confined to the Yangtze, in which fewer than **200** individuals remain).

All of these three species have been assigned the status of endangered species because so many contributing threat factors such as pollution, hunting, ecotourisms, fossil fuel-based water transport systems, capture fisheries, and population fragmentation by dams and barrages. Out of **23** species of crocodilians (crocodiles, gharials, and alligator), **8** species have been recorded from the tropical Asian rivers. All of them are endangered. Other herpetofaunas are diverse also (Belsare 1994), and tropical Asia supports the world's richest assemblage of freshwater turtles and terrapins (Thirakhupt and Van Dijk 1994). Rivers of tropical Asia are also the habitat of the largest (the Mekong giant catfish *Pangasias (Pangasianodon) gigas*) and one of the smallest lotic fishes (tiny cyprinid *Danionella translucida*) in the world. The

Indochinese Peninsula has accommodated **930** fish species in **87** families in several aquatic bodies depicting the regional diversity of fauna (Kottelat 1989).

Total number of fish species in different Asian rivers are very impressive, **viz.**, **290** in the Kapuas River (Borneo), **245** in the Yangtze River, **222** in the Chao Phraya River (Thailand), **150** in the Salween River (Burma), **147** in the Mahakam River (Borneo), **141** in the Ganges River (India), and **115** in the Baram River (Borneo) (Kottelat 1989. Natarajan 1989 Zakaria-Ismail 1994). The river basin of (**802, 900 km2**) the largest river in Asia, Mekong, supports the lives of more than **500** species under **56** genera (Kottelat M. 1989) and perhaps as many as **1200** (Rainboth 1996). Tropical Asia has more than **105** families of freshwater fishes compared to **74** in Africa and only **60** in South America. Among **316** freshwater fish genera recorded from tropical Asia (Kottelat 1989), the top three families are represented by Cyprinidae (**14**7 genera), Balitoridae (**38** genera), and Sisoridae (**19** genera).

The Balitoridae (previously Homalopteridae) is an exclusively Oriental group of small benthic fishes, widespread in fast-flowing waters throughout the region. Although cyprinids occur in large numbers in Asia, they are lacking in the Neotropics, whereas the fishes under Characidae which represent a major component in the fish assemblages in Africa and in the Neotropics are not found in Asia.

Cichlidae, a major component of the fish fauna of Africa and America, is represented by only two species of *Etroplus* in Sri Lanka, although introduced African *Oreochromis* and *Tilapia* are now ubiquitous in their distribution in this area.. The general composition of the benthos of large Asian rivers appears to be similar in such habitats all over the world and includes Tubificidae, Chironomidae (Chironominae), Gastropoda (Prosobranchia), and Bivalvia (Hynes 1970.).

Among meso- and macrocrustaceans, amphipods and isopods are scarce compared to their abundance in north-temperate habitats. Instead, Decapoda, comprising freshwater crabs, shrimps (Atyidae), and prawns (Palaemonidae), occupy a prominent position in tropical Asian rivers and have penetrated fast-flowing upland streams. Benthic community composition in smaller rivers matches Hynes' (Hynes 1970) assertion that "…**one of the most striking features of the faunas of stony streams is their remarkable similarity all over the the world.**"

In tune with such observation, the lotic mollusk fauna of tropical Asia has exhibited some distinctive elements, such as the importance of thiarid (and sometimes neritid) gastropods and corbiculid bivalves. Among aquatic insects, the diversity of plecopteran families is low in tropical Asian streams. The order is typical of cooler, more northern latitudes and is represented mainly by Perlidae (especially Neoperlinae) plus Nemouridae, Leuctridae, and Peltoperlidae. Odonata and Naucoridae (Hemiptera: Heteroptera) are conspicuous elements of the zoobenthos in many tropical Asian streams. Although most invertebrate species are still undescribed, high diversity is displayed by certain taxa. Mammalian diversity in riverine wetlands in different parts of Asia appeared to be very impressive with the occurrence of some as charismatic megafaunas which are mostly included within the threatened categories (**vulnerable** or **endangered** by the **IUCN**, 90 a).

Dudgeon (2000) has prepared a full list of species; among them otters (*Lutra*, *Lutrogale*, and *Aonyx*), otter civets (*Cynogale* spp.), and fishing cats (*Prionailurus* *planiceps* and *P. viverrinus*) are worthy of mention. Other primates such as leaf monkeys (*Presbytis* spp.) and crab-eating macaques (*Macaca fascicularis*) are abundant in riparian forest, while swamp forest is key habitat for orangutans (*Pongo pygmaeus*) in central Kalimantan (Borneo). With around **100** individuals remaining in the wild, this is probably the rarest large mammal in the world (Foose and van Strien 1997).

Other species of megafauna, including Asian elephants (*Elephas maximus*) and Javan rhinoceros (*Rhinoceros sondaicus*), are more wide ranging, but use riverine wetlands during the dry season because of the availability of water and green forage. One habitat of particular importance to some elements of the Asian megafauna is the seasonally inundated, grassy floodplains of large rivers.

The Indian rhino (*Rhinoceros unicornis*) which is rarer than either African species of rhino is confined to such habitats and formerly ranged along the Indus, Ganges, and Brahmaputra Rivers (Foose and van Strien 1997). The historical distribution of the Indian rhino indicates that, in the recent past, significant expanses of swampy grassland mixed up with green moist deciduous forest, within the rivers' associated floodplains in several regions of Asia, provided habitats for a complex assemblage of large grazing animals including rhinos, deer, wild buffalos, etc.

For example, Asian water deer (*Hydropotes inermis*) grazes vegetation on periodically inundated alluvial soils; Pere David's deer (*Elaphurus davidianus*) was restricted to wetlands along the Yangtze River; hog deer (*Axis porcinus*) is found on floodplains and marshy areas with tall grass; and sambar deer (*Cervus unicolor*), which makes opportunistic use of floodplains and riparian forest, often feeds while wading. Species or subspecies of marshland deer [*Cervus (Ruvicervus) duvauceli, C. (R.) eldi, C. (R.) schomburgki,* and *E. davidianus*] are confined to particular river systems.

2.22.7 Impact of Agroclimates on Biodiversity of Indian Rivers

The ecology of Asian rivers is profoundly influenced by monsoons, which create a characteristic pattern of seasonality, predictable periods of drought and water scarcity during the dry season alternate with intervals of increased discharge, when floodplains are inundated during the wet season.

This has important implications for aquatic productivity, although proper knowledge of the effects of monsoons on all elements of the biota is far from complete. There are also implications for the ionic composition of river waters plus the transported organic and inorganic loads. In general, concentrations of major ions are inversely proportional to flow rate and hence decline during the monsoon season.

Seasonal patterns in abundance of phytoplankton and zooplankton in large rivers are related to the monsoon, characterized by wet season with lower numbers due to washout, dilution, and turbidity and a dry season with higher density due to stable ecological conditions with greater light intensity, less turbidity, etc. Likewise, scouring of periphytic algae during wet season spates reduces standing stocks, as in subtropical Australian streams (Mosisch and Bunn 1997). Declines in zoobenthos abundance might be expected during the wet season, at least in small streams, where spates associated with monsoonal rains and tropical storms could initiate catastrophic drift and washout. By contrast, in a second, smaller stream, the abundance and species richness of the benthos increased during the wet season (Dudgeon 1993).

Evidently, there is interstream variation with respect to seasonal fluctuations in zoobenthos densities such that either the wet or the dry season may be the period of greater numbers. Studies that document changes in composition of the lotic flora and fauna from the headwaters to mouth are lacking entirely, although some components of the biota have been investigated. Where a sufficiently wide altitudinal range is considered, there are longitudinal changes in the composition of zoobenthos assemblages, diatoms, bryophytes, and fishes (Ormerod et al. 1994). Bishop (Bishop 1973) noted that clearance of riparian vegetation resulted in a marked decline in benthic invertebrate richness.

2.22.7.1 Zoobenthos: Life Histories, Trophic Relations, and Production

The seasonality and the timing of life cycle events of zoobenthos mostly determined by monsoonal rains for the settlements and colonization of spates and growing up larvae influence the population densities and community composition.

The strategy of small polyvoltine insects, certain atyid shrimps, and some mollusks involves flexible, poorly synchronized life histories of the type that probably represent an adaptive response to streams with variable or unpredictable discharge. Periods of extended recruitment and multiple overlapping cohorts seem typical of many aquatic insects in which water temperatures remain above **15^0** C for most of the year (Yule and Pearson 1996.). Adult emergence prior to or at the start of the monsoon is common to a number of Odonata, Trichoptera, and Ephemeroptera.

Such seasonality involves relatively large species. Compared to larger conspecifics, smaller larvae or eggs are less likely to be crushed or injured by the substratum movement during spates and may be able to seek shelter deep in the hyporheic zone.

Concordance of life histories among unrelated species from three insect orders lends support to the suggestion that timing of adult emergence (and subsequent oviposition) is an adaptive response to avoid spate-induced mortality of mature larvae during the peak of the summer monsoon, a degree of synchrony arising from physiological responses to increasing day length.

Coincidence of reproduction with the monsoon is seen in some freshwater crabs, and shrimps also get the chance of increased habitat availability (inundated floodplain) for hatchlings in large rivers swollen by monsoonal rains. The breeding habitats of these decapods in large rivers are similar to those of fishes and may involve migrations.

Decapods in smaller streams tend to reproduce before the peak monsoon floods, and hatchlings are benthic forms resembling miniature adults. Mollusks also seem to have evolved strategies to cope with the seasonal runoff and water discharge as revealed by the behavioral manifestation of some pomatiopsid snails (*Neotricula*) in the Mekong River which mate during the high-water period, but oviposition does not occur until water levels have fallen.

Other Mekong genera (*Paraprososthenia*) mate before the floods, but egg development is delayed so that recruitment takes place when low-flow conditions prevail (Attwood 1995.). However, it is still remain to be clear whether seasonal or longitudinal changes in zoobenthic community composition have implications for productivity. The **River Continuum Concept (RCC**; Vannote et al. 1990) makes predictions about downstream changes in representation of functional feeding groups in response to changes in the food base (especially allochthonous inputs) in lotic habitats and can serve as a template for comparing Asian running waters with those elsewhere.

The functional organization of benthic communities in shaded streams in tropical Asia have revealed interesting picture with regard to their relationships with ecological factors and exhibited high standing stocks in allochthonous detritus rich habitats depicting differences from that of the biotic communities in unshaded streams (Dudgeon 1989, 1992a; Yule 1996). However, the less occurrence of shredders in the upper course of some tropical Asian streams is a significant deviation from the **RCC** prediction that shredders and collectors should codominate in headwaters. Shredders comprise between **0.1** and **8.8%** of the zoobenthos in Hong Kong streams (Dudgeon 1989; Dudgeon and Bretschko 1995) and are scarce in leaf packs (Dudgeon and Wu 1999).

Even in primary rainforest streams in New Guinea, shredders do not exceed **2%** of benthic populations (Dudgeon 1995a; Yule 1996), and shredders were no more abundant in forested than unshaded streams in Nepal (Ormerod, 1994). If this underrepresentation of shredders is a general feature of tropical Asian rivers, it may reflect trophic flexibility and hence functional feeding group misclassification, that is, the same taxon acting as a shredder or a collector of fine organic material under different circumstances.

Alternatively, a lack of shredders could reflect limited stream retentiveness for leaf litter (Nolen and Pearson 1993), revealing an increased importance of microbes in litter breakdown in tropical streams (Irons et al. 1994), or higher investment in chemical defense by tropical leaves tropical streams (Irons et al. 1994), or higher investment in chemical defense by tropical leaves making them unpalatable to shredders (Stout 1989).

Leaf palatability (as influenced by toughness or tannin content) does affect the composition of invertebrate assemblages colonizing litter in Hong Kong streams, but most taxa are collector–gatherers, not shredders (Dudgeon and Wu 1999). Breakdown rates for the leaf species that have been studied are rapid, with complete disappearance of litter in less than **3** months (and within a month for some species).

The paucity of shredders does not prevent litter breakdown, but the relative importance to this process of microbes, physical fragmentation, and high water temperatures has yet to be determined (Irons et al. 1994). The turnover of zoobenthos in tropical Asian streams is thus higher than that of the univoltine insects for which we have production estimates. The relatively low proportion of shredders in tropical Asian streams suggests that consumption of allochthonous organic matter is unlikely to make a major contribution to zoobenthos production. Food webs in streams and small rivers (Bishop 1973; Costa 1974; Costa and Fernando 1967) involve widespread use of allochthonous foods by primary consumers and a relatively high percentage of nominally predatory forms. However, in several interactions pathways are being determined by the contribution of autochthonous food sources.

2.23 Trophic Interactions: Microbes and Plants

Primary producers capture much of the energy that flows through freshwater food webs, involving innumerable floral and faunal including microbes which in turn take up the responsibility to drive different biogeochemical transformational fluxes, including decomposition and nutrient recycling in aquatic systems.

Some of this freshwater biogeochemistry (production of methane within wetlands by similar trophic interaction) has importance on a global scale because methane and carbon dioxide represent important greenhouse gases. Knowledge about all such organisms is essential as their functional roles help maintaining water quality as well as healthy biodiversity of the riverine tracts.

2.23.1 Archaea

The Archaea, single-celled organisms without nucleus or organelles, usually undertake asexual reproduction by fission or budding. Analysis of ribosomal RNA sequences has taxonomically separated these organisms from the bacteria. Archaea, phylogenetically a close taxa of Eukarya and Bacteria because of possession of similar genes for transcription and translation, have been found to possess the ability to predominate in extreme environments including hot springs, anaerobic and hypersaline water bodies.

The chemoautotrophic forms of these organisms can produce methane from carbon dioxide and hydrogen (methanogens) using inorganic compounds such as ammonium or sulfide as a source of energy. Some groups are able to do photosynthesis, but without generating oxygen gas. Some other groups inhabiting wetlands such as the methanogens have global biogeochemical importance, especially those populations found in wetlands.

2.23.2 *Bacteria*

The Bacteria, the single-celled organisms without a nucleus, represent the ubiquitous and metabolically most diverse group of organisms on earth, characterized in having active biomass (protoplasm) in comparison to other groups of organisms on earth (Whitman et al. 1998). These unicellular organisms exhibit different forms of feeding preferences such as heterotrophs obtaining energy from oxidizing organic carbon, often acting as predators and parasites, or may become autotrophic (chemoautotroph and photoautotroph) and mixotrophic (a combination of heterotrophic and autotrophic activities).

Alongside acting as carrier human pathogens, some of the most important bacteria may become the pathogens to many aquatic plants and animals.

2.23.3 **Cyanobacteria** *(Blue-green Algae or Cyanophytes)*

Cyanobacteria, representing an important group of photosynthetic bacteria, impart tremendous impact on water quality by forming blooms in eutrophic waters, outcompeting other algal forms mainly because of possession of phycobilins, the pigments that absorb light in the green region (where chlorophyll does not absorb).

Cyanobacteria pose difficulty to herbivores for their consumption of this group of bacteria, because of their gelatinous coatings, sometimes endowed with toxins. *Cyanobacteria*, representing an important group of photosynthetic bacteria, impart tremendous impact on water quality by forming blooms in eutrophic waters, outcompeting other algal forms mainly because of possession of phycobilins, the pigments that absorb light in the green region (where chlorophyll does not absorb). Cyanobacteria pose difficulty to herbivores for consume this group of bacteria, because of their gelatinous coatings, sometimes endowed with toxins.

2.23.4 *Protoctista*

The protists include different forms of organisms from single celled to multicellular, including algae (other than cyanobacteria), and the heterotrophic protozoa are included under the taxa.

Various groups of protists are responsible for much of the primary production and nutrient recycling that occurs in aquatic habitats. Traditionally these were split into the protozoa (heterotrophic and unicellular) and the eukaryotic algae.

2.23.5 The Algae

Algae are defined as nonvascular eukaryotic organisms which contain the green pigments, chlorophyll, for undertaking of oxygenic photosynthesis.

The diatoms represent the most common form of freshwater algae under the family Bacillariophyceae which are ecologically extremely important as primary producers in lakes, streams, rivers, and wetlands. Changes in diatom assemblages over time can then be related to changes in climate, water chemistry, nutrient availability, and other factors that influence diatom assemblages.

Other groups of algae mostly belong to families Chlorophyceae and Charophyceae, (green algae and relatives) which range from simple single-celled organisms to complex multicellular assemblages. They are found in the surface of the sediments of all aquatic habitats, even in the rapidly flowing streams as benthic algae and are present as phyotoplankton in the pelagic and limnetic zones of large rivers to small wetlands.

Some species are found mainly in oligotrophic habitats, whereas others are common in eutrophic habitats. Several other groups of algae are found in freshwater ecosystems, including the Cryptophyceae, the Tribophyceae, and the Phaeophyceae.

2.23.6 Protozoa

Protozoa, the single-celled faunal component, are found in large numbers and with higher diversity in nearly every freshwater habitat on earth.

This group can be functionally classified as autotrophs and heterotrophs, but morphologically protozoa include three major groups such as flagellates, ciliates, and species with pseudopodia. The flagellated protozoa (those with one or more flagella) can be divided into two major functional groups. The phytoflagellates include groups that are autotrophic, heterotrophic, and mixotrophic (dinoflagellates, chrysophytes, euglenoids, and flagellated green algae).

The zooflagellates are all heterotrophic. The heterotrophic nanoflagellates are very small zooflagellates that are often the most important consumers of pelagic bacteria and can serve a vital role in nutrient cycling. The ameboid protozoa, including phyla Karyoblastea and Rhizopoda, constitute the largest group of described species of protozoa.

The amoeboid protozoa include those that move by protoplasmic flow and use of pseudopodia. These groups of protozoa are more often associated with benthic habitats and sediments than open freshwaters, but some floating forms exist. Many of the amoeboid protozoa are also important microbial predators.

The ciliated protozoa are characterized by having more than four cilia, which are primarily used for locomotion. Nuclear dualism is a unique feature of the ciliates; individuals have one or more macronuclei and one or more micronuclei. This group contains the familiar *Paramecium* and other free-swimming genera.

2.23.7 Fungi

Fungi is characterized in having nucleated cells, lacking green pigments, reproducing both sexually and asexually thalaoid vegetative structure not differentiated into roots, stem, and leaves, composed of branched filaments surrounded by cell walls containing fungal hemicelluloses or chitin or both. More than **600** species of fungi occur in freshwaters (Wong et al. 1998), which include Labyrinthulomycetes (slime molds), *Ooprotista* (algal fungi), *Ascomycetes* (sac fungi), *Basidiomycetes* (club fungi), and *Deuteromycetes* (imperfect fungi) which are mostly saprophytes, Their functional roles as decomposers, bioremediators, etc. have been well established (Paria et al. 2018; Paria and Chakraborty, 2019). Fungi play important roles in converting several biological derivatives (leaves, woods, waste foods, droppings, and fecal matters of birds and other animals, etc.) and thereby enhancing the fertility status of the soils by the actions of an array of saprophytic fungi in close association with other bacteria. Colonization of fungi softens detritus and increases its nutritional value to make readily available to many invertebrates (Arsuffi and Suberkropp, 1989; Suberkropp and Weyers, 1996). Therefore, fungi constitute one of the major components of nature's microcosm without which life on earth would not have been possible.

2.23.8 Diversity and Adaptability of Multicellular Animals in Lotic System

The fast movement of streams with transparent, cold, and rushing waters lead to cause the almost total absence of waterbirds because of the non-availability of food and rigorosity of the riverine flows, although a good number of smaller animals are observed in this upstream sector of the river which support even very few plants for herbivores, and even a small number fishes are found which are mostly secretive, hiding among rocks and stones at the slightest disturbance. Most of the fishes avoid higher reaches because they cannot negotiate intensity of currents of the flowing streams. The only animals present are those that can climb or fly: frogs and some lizards, insect larvae in the rocky rubble, and occasional dragonflies or damselflies.

Nutrients in the form organic matter, produced by the decomposition of plants' biomass, mostly the falling leaves from the surrounding forests, are supplied to the riverine flows as allochthonous food materials and in turn add sufficient dissolved matters to enable the algae to utilize and grow and to be used by different benthic fauna (aquatic insects, crustacea, mollusks, etc,) and fish that remain hidden under hard bottom substratum. These herbivores that feed on algae or scavengers that feed on any organic materials act as the foods for a number of other predatory animal species. These animals striving to maintain their lives in the fast-flowing water use glue secreted by their bodies to attach themselves with the hard rocks crawl around on with powerful, recurved legs to keep their flattened bodies gripped firmly to the stone, and strongly jawed predators practice grazing on the algae **(Table 2.15)**.

2.23.8.1 Phylum Porifera

Sponges belonging to the phylum Porifera are represented by about **3000** species worldwide of which few (**25**) species inhabit freshwater (Frost 1991). They represent the lowest category of slimy multicellular animals constituted by primitive tissues without any differentiation like other multicellular animals.

Sponges undertake filter feeding and reproduce both sexually and asexually (fragmentation process to produce resistant stages, called gemmules that are resistant to adverse conditions). Sponges provide shelter to a number of other aquatic fauna such as small shrimps, polychaetes, and mollusks within their body cavity from where those animals also harvest waste matters as their foods.

Sometimes, some sponges get attached on the thoracic appendages of crabs and develop the symbiotic relationships from where both get th benefits. Keeping inedible sponges as cover over the body, crabs escape from the attack of the predators, and sponges can change their positions from one ecozone to others to get more foods and oxygen with the movements of crabs.

2.23.8.2 Phylum Cnidaria

All colonial hydrozoa, those found in freshwaters, belong to the class Hydrozoa (Slobodkin and Bossert, 1991; Smith 2001). These radially symmetrical animals are endowed with specialized cells cnidocytes, having cnidocysts (nematocysts), which can fire variously to capture prey by penetrating and releasing toxins from into the bodies of their target organisms.

These small animals predate on a variety of smaller invertebrates such as copepods and cladocerans, by paralyzing the preys with nematocysts.

2.23.8.3 Phyla Platyhelminthes and Nemertea

The phylum Platyhelminthes includes three classes of significant ecological and economic importance: the Turbellaria (free-living flatworms), the Trematoda (flukes), and the Cestoda (tapeworms).

The Turbellaria, very common in freshwaters, includes about **400** species which are distributed throughout the world (Kolasa, 1991) and act mostly as predators or scavengers of dead animals, whereas some smaller forms are omnivores that feed on detritus, microbes, and living or dead smaller invertebrates.

2.23.8.4 Phylum Gastrotricha

Gastrotrichs are found mainly in benthic habitats and are common in the shallow waters including littoral zones of rivers, streams, estuaries, and lakes. Gastrotrichs are among the few animals that can withstand extended anoxia and concomitant exposure to sulfide (Strayer and Hummon, 1991). Gastrotrichs feed on bacteria, protozoa, algae, and detritus. Most genera have cosmopolitan distributions.

2.23.8.5 Phylum Nematoda

Around **2000** species of nematodes (roundworms) are found all over the world in a multitude of ecological habitats such as freshwaters, soils, and marine environments (Pennak, 1978). These meiobenthic faunal components are found in most of the aquatic habitats, including extreme hot springs and snowmelt pools (Poinar, 1991).

2.23.8.6 Phylum Mollusca

The freshwater mollusks represented by soft-bodied, unsegmented animals with a muscular foot include two classes, the Gastropoda and the Bivalvia (clams and mussels). They form an important part of the biodiversity and food webs of many aquatic ecosystems.

2.23.8.7 Phylum Annelida

Annelids are segmented worms possessing true coelom, and their body cavity has thin transverse septa that delineate the segments. These hermaphroditic animals reproduce by cross-fertilization. The freshwater worm like annelids include mostly of the oligochaetes and the hirudinea, most of which burrow through sediment in lotic and lentic habitats and ingest organic particles, but some are important algal feeders or predators.

Some oligochaetes, particularly the tubificid (Naididae) worms such as *Tubifex*, are highly resistant to low $\mathbf{O_2}$ concentrations and high levels of organic pollution. Thus, they are used as indicator species of polluted waters and can be components of biotic indices to assess ecosystem health.

2.23.8.8 Phylum Arthropoda

Arthropods are one of the most successful groups of organisms on the planet, and they are well represented in all continental surface waters.

They are important components of aquatic biodiversity and central to ecosystem function. They are characterized by a chitinous exoskeleton and stiff-jointed appendages (including legs, mouthparts, and antennae). There are three subphyla under the phylum arthropoda in the common freshwaters **viz** the Chelicerata (class Arachnida – water mites and aquatic spiders) and the Uniramia (insects).

2.23.8.8.1 Subphylum Insecta

Many insect orders contain aquatic or semiaquatic species (Merritt et al. 2008). Insects are found in most freshwater habitats, where they are arguably the best studied group of freshwater invertebrates. The majority of the aquatic insects spend most of their immature lives in the water, and the adults emerge from the aquatic environment to mate and disperse.

Mayflies (Ephemeroptera) are very dominant components of the aquatic (rivers and streams) invertebrate communities, serving as an important food source for fishes and the benthic fauna. Mayfly nymphs are distinguished from other aquatic insects by long filaments on their posterior end (generally three) and the presence of conspicuous gills on the abdominal segments. The abdominal gills of mayfly nymphs range from platelike to feathery and to long filaments.

Another unique feature of mayflies is the subimago stage. The Odonata (dragonflies and damselflies) are fantastic predators as aquatic nymphs and terrestrial adults. About one-third of the larvae are lotic and two-thirds are lentic (Hilsenhoff 1988). The nymphs can be distinguished from other aquatic insects by the long, hinged labium that has been modified to eject rapidly and seize moving prey.

The order Orthoptera (grasshoppers, crickets, and others) does not include any truly aquatic forms, but some species are adapted for a semiaquatic existence. The Plecoptera (stoneflies) are important in streams as food for fish and other vertebrates. Some species are predators of other invertebrates, while others are important leaf shredders, which facilitate the decomposition and recycling of materials.

Stoneflies are associated primarily with pollution-free, cool, highly oxygenated running waters. This preference for clean habitats has led to their use in biotic indices for stream water quality and biotic integrity. The nymphs are somewhat similar in body form to mayflies, but can be distinguished from other aquatic insect nymphs by the presence of two long cerci (appendages) on the posterior end of the abdomen and their elongate, often flattened bodies. The gills of stonefly nymphs are generally less conspicuous than those of mayflies, or, if they are obvious, they usually appear as small tufts or fingerlike projections.

The order Hemiptera includes the suborders Heteroptera (true bugs) and Homoptera (plant hoppers, aphids, and others), most of which are terrestrial. About one-third of the aquatic or semiaquatic species live on the water surface, and two-thirds live in the water. All breathe air, so those that live underwater generally use siphons or air bubbles to breathe.

This group is well represented in lentic and lotic habitats, particularly in highly vegetated areas, and they are tolerant of low dissolved oxygen concentrations in the water. The Hemiptera are distinguished by mouthparts that are modified to form a sucking and piercing beak, which is used to pierce plant tissues in herbivorous forms or feed on the blood of animals in carnivorous species.

This group includes some of the most familiar aquatic insects, including the giant water bugs and water scorpions (big enough to prey on small fish and tadpoles), the water boatmen (often seen in shallow littoral zones), and the gerrids (water striders). The order Neuroptera used to include what is now considered a separate order, the Megaloptera (fishflies, dobsonflies, alderflies, and hellgrammites).

Neuropterans are mostly terrestrial, except for spongillaflies, which live in and feed on freshwater sponges. Most species occur in running waters, but some occur in lakes and wetlands. Along with the mayflies and stoneflies, a diverse caddisfly community indicates a clean stream or river.

The free-living caddisflies are mostly predators, those that build cases are primarily herbivores on periphyton or eat dead leaves, and species that spin nets are filter feeders. The Coleoptera (beetles) species with aquatic larval and/or adult stages represent only about **3%** of this mostly terrestrial order. However, there are so many species of beetles in the world that they are significant components of the biodiversity of both lentic and lotic habitats.

The group includes the riffle beetles (Elmidae, with aquatic larvae and adults), the water pennies (Psephenidae larvae, attached to rocks), and the whirligig beetles which live in lakes and wetlands and often feed on aquatic vascular plants and may bore Some adult. The order Hymenoptera (bees, wasps, ants) does not include any truly aquatic species, but some small wasps parasitize aquatic insects, and in some cases, the adult wasp actually swims or crawls underwater to lay eggs in the host.

Most **aquatic** Hymenoptera parasitize larval or pupal stages of aquatic insects such as aquatic flies, caterpillars, and caddisflies. The order Diptera (flies and midges) constitute a large group, to which about **40%** of all aquatic insects belong (Hilsenhoff, 1991). This group is dominated by the family Chironomidae which includes about one-third of all species of aquatic Diptera.

The Diptera also includes many aquatic larvae with adults that are nuisance species and important disease vectors, including Simuliidae, biting midges (Ceratopogonidae), and horseflies and deerflies (Tabanidae). Some mosquitoes are very important vectors of diseases such as Dipterans show a great degree of diversity and adaptation to different types of aquatic habitats.

2.23.8.8.2 Subphylum Crustacea

The subphylum Crustacea is a mostly aquatic group with abundant and diverse freshwater forms. This group includes some species that are critical in food webs and ecosystem processes; cladocerans and copepods are key primary consumers in many lakes and ponds, and decapods (crayfish and others) are important omnivores in benthic food webs of many rivers, lakes, and wetlands.

The crustacean taxonomic groups considered here are the Ostracoda, Copepoda, Branchiopoda, Decapoda, Mysidacea, Isopoda, Amphipoda, and Bathynellacea. The

Ostracoda are benthic species that are covered by a carapace often composed of chitin and calcium carbonate that is modified into two shells or valves that cover the body.

Ostracod shells are particularly well preserved in sediments; paleolimnologists make use of them as indicators of ancient environments, and these fossils are the oldest known microfauna (Delorme, 1991). Ostracods are found in most aquatic habitats, including temporary pools, ponds, lakes, rivers, and groundwaters. The Copepoda is a group of microcrustaceans that can be important components of zooplankton in both freshwater and marine systems, but most freshwater species are found associated with the benthic zones of streams, wetlands, and groundwaters. The copepods can be herbivorous, detritivorous, carnivorous, or parasitic.

Parasitic forms such as *Lernaea*, a common ectoparasite on fish, are highly modified and do not resemble free-living forms whatsoever. Reproduction in copepods is usually sexual. The fertilized eggs hatch into a larval stage called a nauplius. Some copepods can produce eggs that are resistant to drying, and copepods are often among the first invertebrates to appear in freshly inundated habitats such as intermittent streams and wetlands. Six naupliar stages are followed by six copepodite stages (the last being the adult stage).

The Branchiopoda includes the Cladocera (water fleas) and the fairy, tadpole, brine, and clam shrimps. This order is generally composed of small crustaceans with flattened, leaflike legs. Cladocerans are often extremely important zooplankters in rivers, streams, and lakes. Reproduction in many cladocerans is parthenogenic for most of the year.

Thus, females are encountered most often in nature. At times, often when conditions are suboptimal for growth, males and sexual females are produced, and sexual reproduction occurs. The fertilized eggs are encased in a resistant ephippium that can remain dormant until conditions once again are favorable for growth and reproduction.

2.24 Behavior and Interactions Among Microorganisms and Invertebrates

However, interactions within and among species are being considered as the thrust area in field of aquatic ecology and are mediated by behavior and metabolism which are shaped by evolution. Many interactions among the aquatic organisms are based on behavioral responses that are mediated by motility and responses to chemicals.

2.24.1 Interaction Types in Communities

The interspecific interactions among aquatic biota are initially demarcated as trait-mediated and density-mediated interactions. Density-mediated interactions are those which are based on changes of populations of one species in response to another.

Trait-mediated interactions are determined by evolved traits in response to selective pressure associated with the interaction. In general, density-mediated species interactions are important from the need of managing organisms and also for making prediction on the immediate effects of disturbances on organisms. The reason behind the difference of these two types of interactions is that population regulation does not have any determining effect on natural selection for specific traits.

2.24.2 Predation and Parasitism Including the Microbial Loop

Microbial food webs are central to nutrient cycling and energy transfer in most aquatic systems. Microbial loop, in streams, rivers, and, wetlands, involves the transfer of energy, carbon, and other nutrients through the microbial food web. The idea that microbial assemblages have an active role in transfer of energy in aquatic systems has changed the way that food webs and energy transfer are viewed..

The microbial loop is essential to scavenging dissolved organic compounds in water and returning this organic material to the food web. Bacteria release a large variety of enzymes that allow use of organic carbon (Münster and DeHaan, 1998). The majority of organic material originating in terrestrial environments that enters aquatic environments must be processed by microbes.

Organisms that eat these bacteria and fungi, or use them in their guts, return the organic carbon (or a portion of it) back into the food web. Without the microbial loop, the bulk of the organic carbon in aquatic ecosystems would be tied up in nonliving dissolved and particulate organic material. The microbial loop can also be important to understanding how pollutants move into food webs (Wallberg et al. 1997); bactivory can increase rates of bacterial activity (Ribblett et al. 2005), increasing rates that pollutants are processed. Microbial food webs are a key supplier of carbon in stream food webs (Bott, 1995; Sigee 2005). Bacteria and fungi break down wood and leaves that enter streams, making the carbon available to primary consumers. Energy transfer via the microbial loop in streams could even be more efficient than in planktonic systems (Meyer 1996).

The microbial loop is also responsible for a significant amount of energy flow in wetlands, with amoebae rather than ciliates and heterotrophic flagellates predominating (Gilbert et al. 1998). The microbial loop is the primary energy pathway in many groundwater habitats (Gibert et al. 1994) including hyporheic sediments (Findlay and Sobczak, 2000).

2.25 Energetetics in Pelagic and Benthic System: Different Foraging Biotic Categories

Understanding on the controls and rates of consumption of very small particles in planktonic systems in the pelagic realm of aquatic ecosystems reveals that more energy is required for survival and reproduction of an organism that consumes small particles when **(1)** particles are dilute, (**2**) particles are low quality, (**3**) particles are small, (**4**) temperatures are low, and (**5**) particles that protect themselves are toxic. These factors all interact, and proper evaluation of their interrelationships helps in characterizing planktonic food webs.

In contrast to pelagic habitats, benthic habitats contain larger organisms that are able to process considerable amounts of sediment and thus capture a significant number of bacteria per unit time. Invertebrate animals by virtue of their continuous foraging activities exceed their ability to ingest bacteria. Different food capturing devices as practiced by different maco-metazones are as follows:

1. **Scrapers**: These organisms often referred to as grazers scrape biofilms which can consume a wide variety of microbial species. This faunal category includes snails, some tadpoles, and many types of immature aquatic insects which usually feed on substrata surfaces, in search of algae, heterotrophic components of biofilms, and associated deposited organic sediments. The nutritional ecology of scrapers based on their nutritional requirements has appeared to be complex because of differential assimilation of ingested materials.

Some algivorous scrapers (fishes and tadpoles) derive considerable nutrition by grazing microbes associated with biofilms and detritus (Evans-White et al. 2003; Whiles et al. 2010). Many aquatic faunal components have adopted the mode foraging activities of the scrapers; the pronounced example of which are mollusks (gastropods) which possess and operate with a unique feeding structure such as radula, composed of bands of rows of tiny teeth.

Grazing fishes such as *Campostoma anomalum* and similar other tropical species also have evolved subterminal mouthparts as an effective feeding organ for scraping. Scrapers feeding on periphyton can greatly reduce algal biomass in freshwater habitats. Scrapers can also increase biomass-specific algal production through the removal of senescent tissues, excretion of nutrients during feeding, and altering algal community structure (Lamberti and Moore, 1984; Steinman, 1996).

The bioturbation activities of scrapers because of their feeding activities reshuffle the nutrients among different strata of sediments by producing suspended materials and resuspend deposited particles.

2. **Shredders**: Shredders are those faunal components that eat detritus, either in the form of leaves and wood or as finer benthic organic materials, as microbial predators, in order to derive their nutrition (Cummins and Klug, 1979). Many freshwater shredders including many crustacean and insect species feed on coarse detritus such as wood and leaves and also take active roles in the decomposition

of organic materials. Experimental studies have revealed that removal of invertebrates, including shredders, from a headwater stream resulted in significant reduction of the rate of leaf litter decomposition and a sixfold decline in fine particle concentrations in the stream water (Cuffney et al. 1990). Microbes associated with plant detritus have been termed the "peanut butter on the cracker" because shredders feeding on this material gain more protein from the microbes than the detritus "cracker." Shredders tear leaf and wood material up before ingesting it. This increases rates of microbial degradation of cellulose in their guts and also stimulates breakdown of the remaining material by increasing surface area for further microbial colonization.

Owing to the consumption of relatively small quantity feed, shredders also have high ingestion rates, which facilitate breakdown of coarse organic materials and generation of fine particulates (Wallace and Webster 1996). Feeding activities of shredders generate small particles that are fed on by a variety of collectors such as midge larvae and filter-feeding caddisflies and mussels.

Shredders, such as caddisflies (Trichoptera) and stoneflies (Plecoptera), make up a large group of insect larvae. They feed on coarse particulate organic matter (**CPOM**), mostly leaves that fall into the stream. The shredders break down the **CPOM**, feeding on the material not so much for the energy it contains but for the bacteria and fungi growing on it.

Shredders assimilate about **40%** of the material they ingest and pass off **60%** as feces. Broken up by the shredders and partially decomposed by microbes, the leaves, along with invertebrate faces, become part of fine particulate organic matter (**FPOM**). Drifting downstream and settling on the stream bottom, **FPOM** is picked up by another feeding group of stream invertebrates, the filtering collectors (larvae of blackflies; Simuliidae), and gathering collectors (larvae of midges). Collectors obtain much of their nutrition from bacteria associated with the fine detrital particles.

Shredders that burrow enhance organic matter and associated microbial activity in sediments in much the same fashion as earthworms in terrestrial systems (Wagner, 1991). In lotic systems, shredders enhance the entrainment and downstream movement of materials by reducing particle sizes. In lotic system, allochthonous litter inputs and subsequent decomposition are often primary energy flow pathways (Vannote et al. 1980; Webster et al. 1999).

3. **Collector–gatherers**: Freshwater organisms which harvest small deposited organic particles as their foods from the surface of substrata are termed collector–gatherers. Microbial assemblages along with other green biomass constitute the food particles that are rich in cellular material and more biologically active. Oligochaetes and chironomids, being the typical representatives of this category, process large quantities of sediments and assimilate the microbial component and also other digestible organic materials present in the sediments.

These groups in conjunction with shredders convert detritus and microbial biomass to invertebrate biomass and thereby play significant roles for larger consumers such as fishes and aquatic birds, which rely heavily on these groups for food

(Wallace and Webster, 1996). While shredders and collectors feed on detrital material, another faunal group, the grazers (larvae of beetles and caddisfly), feeds on the algal coating of stones and rubbles.

4. **Filter feeders**: Filter feeders are those organisms which can harvest their food materials by filtering the overlying water loaded with food (living or nonliving) by an intricate mechanisms added with well-designed feeding appendages.

Rotifers, ostracods, copepods, and Cladocera as zooplankton and Bryozoa (Ectoprocta and Entoprocta) different bivalves as benthic fauna have many feeding appendages that circulate and filter water in order to procure the targeted food particles. Examples of filter feeders in riverine ecosystem include clams, mussels, larvae, and adults of different aquatic insects which feed mainly on microbial particles and thereby strongly influence energy flow and nutrient cycling in freshwater habitats. In the water bodies with higher current of water, filter-feeding assemblages are dominated mostly by passive filter feeders, utilizing flow water loaded with food particles without affording much efforts (Strayer et al. 1999).

5. **Competitors and competition**: Competition being a very important type of species interactions in aquatic communities has been projected as a key driving force in bringing evolution (Connell, 1983; Schoener, 1983). Initiation of competition in many aquatic organisms belonging to different which are in need of similar resources as food and shelter and even among individuals of same species because of similar reproductive requirements.

There are two forms of competition.

(i) **Exploitative competition**: It is that kind of competition among the organisms that are both exploiting the same resource. Exploitative competition in between two organisms using the same resource results in benefits of one organism and harm to the other.
(ii) **Interference competition**: Direct negative effects on other organisms are termed interference competition. Predation is generally referred to as exploitation.

The theory put forward by Tilman (1982) on assessing the eco-biological outcomes of exploitative competition pertaining to the simultaneous consumption of more than one resource helps explain the possible manifestation of unequal abilities displayed by those organisms to use nutrients. Interference competition It is difficult to relate interference competition microbes.

Through interference competition, one organism is able resist the attack of a potential competitor through the production of toxic compounds such as allelochemicals (organic compounds that influence and arrest growth rates of other organisms), produced in planktonic, benthic, and algal communities which (Gross, 2003).

The chemically mediated interaction especially by allelochemicals is known as allelopathy which triggers and accelerates successional sequences in phytoplankton (Rice, 1984). Allelochemicals, a biochemical entity after being produced by phytoplankton for the purpose of reducing competition, find their ways to go out of the body through the process of excretion when cell densities reach to the optimum densities to bring total concentration of it in the water to an effective level, as encountered during algal blooms (Lewis, 1986).

6. **Mutualism**: Mutualism, being a unique interactive association between two organisms where two or more species get the benefits from each other. Such interaction rarely occurs in aquatic communities in comparison to other interactions. In nature, diversity in respect of benefits derived from the interactions involving microorganisms is very much prevalent. Mutualistic relationships in respect of the roles of nitrogen-fixing bacteria or cyanobacteria with plants can be exemplified as the most likely interaction involving nutrient cycling.

Such interactions are also evident from the interaction between the water fern *Azolla* and the nitrogen-fixing heterocystous cyanobacterium *Anabaena azollae*; occurrences of nitrogen-fixing cyanobacteria in the diatom *Epithemia*; and association of nitrogen-fixing microbes, with the flowering wetland plant *Gunnera* and the cyanobacterium *Nostoc* (De Yoe et al. 1992; Meeks, 1998).

2.25.1 Adaptation of Organisms in Flowing Water

The lotic water inhabiting organisms have evolved unique adaptation to thrive well in water current by developing several devices to stick themselves with hard structures not to be swept downstream. They are mostly with a streamlined body form which offers less resistance to water current and are provided with suckers, bristles, spines, etc. for adhering firmly in their habitats. The larval forms of many aquatic insects possess extremely flattened bodies with broad, flat external appendages for that clinging to the undersurfaces of stones, gravels, wooden logs, stems of water plants, etc. where the current is comparatively low. The larvae of certain species of caddisflies (Trichoptera) wrapped themselves by constructing protective cases with the sediments and their own secretion to cement them to the bottoms of stones and gravels. Moreover, sticky undersurfaces help benthic fauna clinging rigidly and move about with the shifting of stones, gravels, and sands by the current of water. All the inhabitants of fast water-flowing streams require higher concentrations of dissolved oxygen and also in intimate contact of moving water to keep respiratory surfaces always moist in continuous contact with the oxygenated water. Invertebrate inhabitants are classified into four categories based on their feeding habits.

2.26 Trophic Relationships: Different Interpretations

Food webs can be simplified into trophic levels for ecological analyses. Traditionally, levels include primary producers (photosynthetic organisms), decomposers or detritivores (consume dead organic material), primary consumers (herbivores or grazers), and secondary consumers (eat primary consumers). Owing to possessing of different categories of feeding processes, species can be assigned fractional trophic levels (primary producers are assigned level):

1. Herbivores level
2. Predators of the herbivores level
3. Animals that eat half herbivores and half primary producers level

The idea of trophic levels, regardless of its weaknesses, has proven particularly important in analysis of the effects of top consumers on organisms lower in the food web.

2.26.1 The Trophic Cascade

In 1880, Lorenzo Camerano postulated that animals can control the biomass of lower trophic levels and diagrammed how a carnivore can control herbivore populations and this can have a positive influence on plants (Camerano, 1994). The trophic cascade highlights the idea of the cascading effect of predation at the upper level of food chains down to the lower levels of food chain. Control of primary production by abiotic factors such as nutrients or light is called bottom-up control. Control of primary producers from the upper levels of the food chain is referred to as top-down control, which is sometimes used interchangeably with trophic cascade.

These ideas entered modern ecology in a key paper by Hairston et al. (1960), which argued that plants dominate terrestrial systems because predators keep herbivores in check. These arguments were extended to the idea that even numbers of links in food chains will lead to higher biomass of primary producers (Fretwell, 1977).

Brooks and Dodson (1965) documented that increased predation pressure by a planktivorous fish led to much smaller zooplankton species. Smaller zooplankton are less efficient grazers, and the population size shift resulted in increases in chlorophyll. The underlying operating principles of trophic cascade are being used to develop biomanipulation concept for improving the water quality by controlling the fish community and other biofouling organisms to achieve sound ecological health. The general approach is to encourage the populations of larger fishes that consume zooplanktivores.

The trophic manipulation leads to increases in large grazing zooplankton (average body size of zooplankton increases). The large grazing zooplankton can consume more phytoplankton. Consequently, there is an increase in water clarity related to a decrease in suspended algae. Food web manipulation in concert with nutrient control can lead to significant increases in water quality over decades (Lathrop et al. 1996).

The key issue in propagation of bottom-up or top-down effects in aquatic ecosystems seems to be how well the effects are transmitted between the zooplankton– phytoplankton link (Carney, 1990; Elser et al. 1990; Elser and Goldman, 1991), although the trophic cascade may also break down at the link between zooplankton and fish (Currie et al. 1999).

Empirical analysis suggests the grazer link is where top-down and bottom-up effects are decoupled (Brett and Goldman, 1997). The trophic cascade can extend to physical and chemical aspects of both lentic and lotic aquatic ecosytems. Low zooplankton grazing rates can lead to greater influx of atmospheric $\mathbf{CO_2}$ related to increased algal biomass with high photosynthetic demand (Schindler et al. 1997).

Predation by zooplanktivorous fish can increase nutrient supply by excretion, enhancing algal production both by indirectly lowering grazing pressure and by directly providing nutrients (Persson, 1997; Vanni et al. 1997; Vanni and Layne, 1997). An example of how complexity of food webs alters efficacy of lake biomanipulation is the fact that large fishes reproduce well when their numbers are increased for trophic control of zooplankton.

The young by virtue of their voracious feeding as zooplanktivorous, can reverse the effects of the biomanipulation, at least temporarily (Hansson et al. 1998). Consideration of temporal and spatial scale can also alter the response of food webs to manipulation. For example, pulses of nutrients can have different effects depending on food web structure and their timing (Cottingham and Schindler, 2000).

If zooplankton have time to respond to nutrient enhancement of phytoplankton growth, further pulses of nutrients will have little influence. If predation on zooplankton is high, they may not be able to suppress ephemeral phytoplankton blooms in response to nutrient pulses (Strauss et al. 1994). Top-down effects can also occur in benthic habitats of lakes. Snails remove littoral periphyton and are susceptible to predation by sunfish.

When sunfish are excluded, algal biomass decreases significantly (Brönmark et al. 1992). Since sunfish are prey for large piscivores, high biomass of large piscivores could lead to a decreased biomass of periphyton through the tropic cascade. Clear examples of the trophic cascade have been documented for streams.

In some California streams, exclosure of fishes resulted in decreases in *Cladophora* (a filamentous green alga) biomass because predation on midge larvae was decreased, and the midge larvae suppressed *Cladophora* (Power, 1990a). These results are consistent with the findings that algal biomass, started increasing in the pools having no feeding pressure but decreased without bass in the pools and high numbers of stonerollers.

Finally, when bass were tethered in a pool, algae proliferated only in the areas around the bass, but not outside their reach (Power and Matthews, 1983). The tethering effect may have occurred because bass also can control crayfish in this system, but the effect is still a top-down effect. Grazing by the stonerollers led to lower algal biomass, more cyanobacteria, less heterotrophic bacteria, higher invertebrate density, and less particulate organic material, so the effects of this trophic cascade extended to basic stream ecosystem properties (Gelwick and Matthews, 1992).

The numbers of trophic levels have led to develop high producer biomass. A case of bottom-up control was demonstrated in which organic contamination of an aquifer stimulated bacterial and protozoan production relative to nearby uncontaminated groundwater (Madsen et al. 1991). Protozoa depressed bacterial abundance, but increased nitrification rates in a laboratory study using groundwater and associated sediments (Strauss and Dodds, 1997). As more groundwater food webs are described, numerous cases of top-down and bottom-up control are likely to be documented.

2.27 Biodiversity Conservation and Its Contribution

2.27.1 Consolidation of Initiatives for Biodiversity Conservation Across the World

Extinction or near-disappearance of some of the charismatic species such as the dodo on the island of Mauritius and cheetah from the Indian subcontinent have drawn the attention of not environmental activists but also the peoples representing different tiers of the society. The depletion of all these emblematic species is caused by several reasons like habitat destruction, especially deforestation, intensive hunting, and ecological perturbations due to the explosive population growth, utilization of previously untouched territories for urbanization, and increasing efficiency of technological means of exploitation floristic and faunistic components. Since the the middle of the **1960**s, conflicts, debates, and discourse were augmented with more intensity in order to make effective propagation and awareness building by consolidating and echoing public opinion around through the combined roles of international like International Union for Conservation of Nature (**IUCN**), World Wildlife Fund (**WWF**), etc.; national (respective governmental departments); and the nongovernmental organizations (**NGOs**) for natural protection and conservation of endangered charismatic animals (tigers, elephants, dolphins, rhinoceros, pandas, etc.). In the beginning, keeping aside traditional ethical and emotional considerations as the triggering factors for the effective biodiversity conservation, steps were taken in motivating and encouraging local peoples, environmental planners and policy makers, social scientists, conservation biologists, and politicians to enact changes. One such approach was to identify, highlight, and demonstrate the potential and contribution of biodiversity as ecological service providers and the usefulness of such benefits for the well-being of humankind.

In tune developing perspectives of biodiversity conservation, several new terminologies were emerged such as **useful nature**, which acquired major significance in inviting and solidifying the economic interest in biological diversity. Naturalists, conservation biologists, and **NGOs** without having that much knowledge base pertaining to the quantified assessment and valuation of the biodiversity wealth started seeking the active support from the social scientists and economists for the formulation of economic models incorporating the convincing arguments based on the goods and services rendered by biodiversity. This was in contrast to the initial perceptions akin to the industrial interest in getting profit by using biodiversity as potential source of revenue for patents on forms of life. The first Article (No **1**) of **Rio conference in 1992**, by summing up all the debates polarizing around the economic stakes towards exploiting the values of nature, emphasized the "**fair and equitable sharing of the benefits arising out of the utilization of genetic resources embedded within biodiversity wealth by developing appropriate biotechnological tools coupled with the appropriate mechanism for the transfer of relevant technologies, inflicting all rights over the biodiversity resources and also to develop technologies, enjoying appropriate funding**." Therefore, biodiversity resources are now being considered as the raw materials for several kinds of production processes (agriculture, pharmaceuticals, food processing, cosmetics, etc.). However, in the realization of the potential of biodiversity as the primary resource base for developing industries and boosting of economy, different nations have started colliding over this domain because of the unequal and uneven global distributional patterns of the resources, most of which are found in the southern hemisphere countries, while the main user countries, endowed with modern biotechnology industries, having multinational enterprises, are located in the northern hemisphere. This has resulted in unscrupulous trading of biodiversity resources from the countries of the southern hemisphere which is required to have internationally acceptable practice of **biopiracy**.

2.27.2 Sustainable Management of Biodiversity

Sustainable and resilient ecosystems are in need to maintain its ecological structure and function over time with the prime aim at providing required societal benefits and expectations. In order to arrest biodiversity loss and the ecological consequences of environmental degradation, integration of relevant components of natural and social science concerned for the conservation is required to become more effective in today's human-dominated world. The systematic and strategic conservation efforts for the protection, maintenance, and preservation of natural resources of the earth aims at restoring and maintaining the balance between human requirements and the other species in the world. Such conservation efforts alongside arresting the loss of biodiversity also ensure ecological stability by protecting diverse biotic components of the communities. A community composed of only a few species will consist of only simple food chains in which each predator has only a single prey species. The chance extinction of that single prey species may become one of the reasons of the extinction of its predator. This, in turn, will lead to the extinction of that predator's predator and so on. By way of contrast, in a biotic community the food webs are complicated where there are many interacting species.

2.27.3 Constantly Changing Living Conditions

The **ordinary** living conditions of a species are sufficiently changeable to cause constant renewal of its basic life support resources, even in the absence of global changes in the environment. This is known as the **Red Queen effect**. The constant need and urge to improve and refine food capturing mechanism has appeared to be the main driving force behind the innovation of living things which explains the amazing feats of capability of the species to cope with the changing ecological setups. For example, there is a real “arms race” between predators and prey. The former are constantly improving their sensory equipment, their speed, their strategies, and even their poisons. The latter respond to this by refining their camouflage, their escape techniques, and their ability to detect danger and produce antidotes.

The appearance of a new species of predator with higher efficiency in an ecosystem has found to impart considerable impacts on existing biotic community even by changing the prey choice of less efficient existing predators present in the community by switching over to prey those herbivores which were earlier ignored by them.. The increased scarcity of these herbivores might favor certain plant species, which will in turn have a knock-on effect on certain insects and so on. All the members of a community are thus ultimately affected by the newcomer and this is how species can disappear.

2.28 River Biodiversity: The Need for an Assessment and Awareness

After almost three decades of the Earth Summit, the **Convention on Biological Diversity (CBD)** came into force to facilitate the conservation of biological diversity on the earth with a transparent recommendation for the fair and equitable sharing of benefits derived from the bioresources of this world as a prerequisite for sustainable development.

It is now an established fact that the loss of biodiversity from global environment in general and freshwater ecosystem in particular has progressed at an accelerating rate because of habitat alterations due to drastic changes in land-use patterns, pollution load from point and non-point sources, and bioinvasion. In river ecosystem, out of a myriad of biodiversity components, microbes by virtue of their overwhelming dominance in number and mass act as the leading actors in ecosystem functioning, such as production and mineralization of organic matter, which are often regarded as ecosystem engineers altering aquatic environments.

Although river ecosystems in its different forms and function are blessed with invaluable biological diversity, modern human activities have resulted in considerable crisis of biodiversity loss worldwide, which in turn leads to deterioration of ecosystem functioning and thereby of ecosystem services. In the face of such human disturbances, such ecosystem alterations because of human-mediated disturbances are often catastrophic, and this phenomenon is known as ecological regime shift.

In such context, one of the major tasks before the ecologists, limnologists, and conservation biologists is to undertake extensive research blending field-based ground truth surveys with laboratory experimentations to understand how human-mediated environmental changes can induce regime shifts in freshwater ecosystems in general and river ecosystem in particular to evaluate how their biological diversity, especially intraspecific phenotypic diversity, affects ecosystem resilience, i.e., dampening the incidence and intensity of **regime shifts**. However, concerted efforts and committed actions towards developing awareness and proper action for biodiversity assessment and conservation of depleting biodiversity components are taking into consideration habitat fragmentation leading to genetical errosion in the depleting populations, retardation of biodiversity-based ecosystem services, and the consequent decay of entire ecosystems.

All of these are being more and more acknowledged by practitioners, decision-makers, and society in general which are in tune of **Strategic Plan for Biodiversity** (**2011–2020**).

2.28.1 Species Extinction and Causes: Destruction of Habitat

Extinctions are not abnormal – quite the reverse. During the period of extinction, species frees up an ecological niche, which can then be filled by new species. The mass extinctions of the past were always followed by active phases of such spectrum of new speciation. Proof of this is the extraordinary rise that followed the disappearance of the large reptiles of the Mesozoic Era.

The primary cause of species extinctions is habitat destruction, the largest cause of which the drastic land transformation in tune with human population explosion, urbanization, industrialization, expansion of agricultural, etc.

According to the **United Nations Food and Agriculture Organization** (Global Forest Resources Assessment 2000), the net loss in forest area at the global level during the **1990**s was an estimated **94** million ha – an area equivalent to **2.4** percent of the world’s total forest.

Aquatic ecosystems have faced destructive pattern of changes because of pollution (eutrophication, pesticides, fertilizers, sewage, detergents, heavy metals, etc.), alongside several construction activities like dredging, filling of wetlands, dams, hydroelectric projects, etc.

2.28.2 Introduction of Invasive Species: Susceptibility of Species Extinction

The susceptibility of species to extinction differs from species to species and is dependent on a number of life history characteristics that influence their vulnerability to human activities as well as natural catastrophes. Based on the pattern of origin and distribution, species are of two types:

1. **Ubiquitous:** Species is with geographically widespread distribution and are less threatened because of their ability to change places overcoming the odds acting of any habitat.
2. **Endemic**: A species found to occur naturally in a single geographic area and no other place is said to be endemic to that location. Endemic species are particularly susceptible to extinction because of a loss of habitat for that species. In the realm of biodiversity studies, endemism (an evolutionary phenomenon leading to the development of endemic species) deserves special attention as it involves a number of eco-evolutionary processes as mentioned below.
3. **Isolation:** Segregation of animal populations from one another by the insurmountable barriers like oceans, mountains, large deserts, large rivers, etc. These barriers may be ecological (specialized ecological niches prevent intermixing of populations between different habitat zones) and reproductive (incompatible breeding seasons separate populations reproductively).
4. **Disruption of gene flows**: Different forms separating mechanisms on segregated populations ultimately result in blocking the exchanges of genes and consequent development endemic species through the operating forces of evolution.

Species with one or few local populations are more vulnerable to extinctions than the species with many local populations because of some ecological perturbations and disturbances (fire, flood, disease outbreaks, etc.). Species that migrate seasonally depend on more than one habitat located at different geographic areas and face the problems of extinction if one of these habitats is destroyed. Some species have very specialized habitat requirements, making them extremely susceptible to habitat alterations. Often, these habitats are scattered and rare across the landscape or regions. Species that require a large home range are often endangered due to habitat fragmentation. Species that are hunted or come into conflict with human needs and activities are also vulnerable to extinction (Smith and Smith, 2006).

2.28.3 Extinction Modifies the Ecological System

In the end, the disappearance of species is only partially responsible for the disappearance of ecosystems. In theory, it is possible to create countless different ecosystems using the same species, by simply varying predatory relations, habitat occupation, relative densities, behavior, and so on. While it is true that the biodiversity of a country or a territory is defined by the number of species it contains, it is also defined by the diversity of its ecosystems. A territory containing a variety of ecosystems is obviously more diverse than another more uniform area. And recreating an ecosystem that has disappeared is no more possible than bringing back to life an extinct species.

2.29 Threatened Species: Criteria and Categories

It is difficult to assess accurately whether a species is "**threatened**," or indeed to what extent it is at risk. The **IUCN** has been working on this task for over **50** years.

2.29.1 The IUCN Red List

The adjective "**threatened**" conveys a certain notion of urgency, which is difficult to quantify, because there are many different situations in nature: abundant species that are declining, rare species whose populations are growing, species that appear stable but whose habitat is deteriorating rapidly, and so on. For over **50** years now, the **IUCN** (International Union for the Conservation of Nature, whose official name was changed to "**The World Conservation Union**" (**IUCN**) in **1990**) has been assessing the preservation status of living organisms. It publishes the **IUCN Red List** of Threatened Species, which is constantly being updated (more than **10, 000** scientists and experts from over **180** countries volunteer their services to its **6** global commissions), and together with its serious and objective approach, the **IUCN** has become a respected international source of.

2.29.2 Categories Defined by Five Criteria

The IUCN has defined criteria which allow each country to assign a category to every species on its territory (**Fig. 2.9).** These criteria take into account the main elements which define a species' state of health. They are number of individuals, fluctuation of the population, size of the geographical range, fluctuation in the size of the range, and the extent to which populations and habitats have been fragmented.

A species only needs to fulfill one of the five criteria defining any given category for it to be included in that category. It does not matter if this species fails to meet the other criteria or if data relating to the other criteria is not available. This system has one big advantage: species for which the number of individuals has not been counted, but whose range is restricted and, in rapid decline, can thus be included in the list. Although legitimate scientific estimates are allowed, fieldwork such as censuses and research into the species' distribution must still be carried out.

However, the acquisition of this data is often costly, and the number of species assessed still remains disappointingly low.

2.29.3 Conflicts of Interest

The need to maintain biodiversity is supported by substantial ecological and economic arguments. Inevitably, practical efforts to conserve species come up against conflicts of interests. Depriving poor populations of a natural resource, whether overexploited or not, can constitute a real threat to their well-being – especially where certain forms of hunting, fishing, collecting, firewood gathering, or farming are forbidden. In the absence of compensatory measures, prohibitions of this kind can have drastic consequences. More often, conservation gets in the way of private interests that have no vital social dimension. Far more receptive to those arguments in favor of developmental progress of human beings than to those of environmentalists, who are often seen as idealists with their heads in the clouds. However, healthy ecosystems provide a wealth of free, natural resources that are essential for human communities; the cost of replacing these resources would be astronomical.

2.29.4 Categories of Threatened Species

Threatened species (**Fig.** 2.9) may belong to any one of the four categories, viz., critically endangered, endangered, vulnerable, and rare.

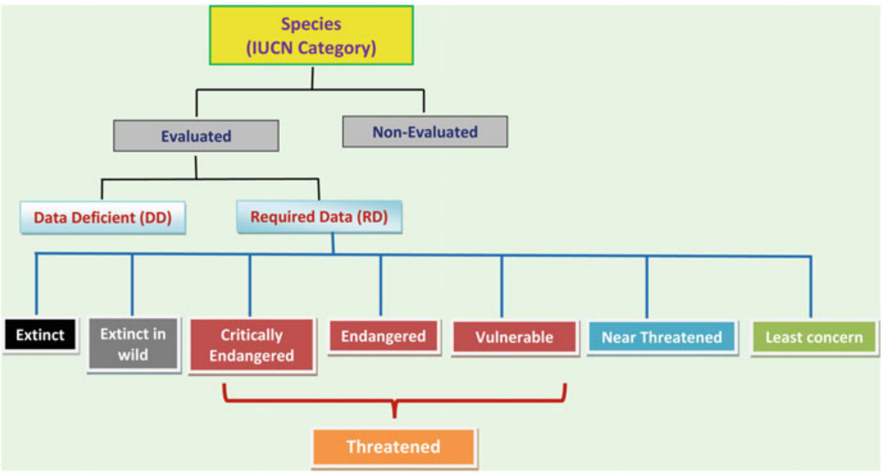

Fig. 2.9 : Different IUCN conservation categories of species

1. **Critically endangered**: The animals correspond to those species which are at greatest risk of extinction in the world. These species have a **50%** or greater probability of extinction within **10** years or **3** generations, whichever is longer.
2. **Endangered**: The taxa is in danger of extinction and whose survival is very much at risk, and they are deemed to be in immediate threat of extinction because of the continuity of action of the operating causal factors. It has been estimated that the endangered species display a **20%** probability of extinction within **20** years or **5** generations.
3. **Species**: This taxa is like to move into the endangered category within a short period of time if the casual factors are allowed to operate at the present rate. These species have a **10%** or greater probability of extinction within **100** years.
4. **Rare**: The taxa residing at a restricted geographical area with depleting population but not belonging to either endangered or vulnerable categories, but are at risk.

Assignments of species to any one type of these categories require at least any one of the following types of information:

1. Observable decline in numbers of individuals
2. The geographic area occupied by a species and the number of populations
3. The total number of individuals alive and the number of breeding individuals
4. The expected decline in the numbers of individuals if current and projected trends in population decline or habitat destruction continues
5. The probability of the species going extinct in a certain number of years or generations

2.30 The Interaction of Man vs Nature: The Sustenance of Biodiversity

Since every person sees his or her surroundings from a unique point of view. Universally acceptable definitions of ecosystem and ecosystem approach cover very broad and holistic pragmatic initiatives, involving natural or artificial subdivisions of the biosphere with boundaries arbitrarily defined to suit specific purposes. Sharing and interconnectedness within the biosphere promote the overlapping of the boundaries of ecosystems. The perceptions and behavioral attitudes of human society nearer to the flowing rivers and river basins have been transforming over the last few decades from an environmental approach to an ecosystem approach for systematic, strategic, and effective planning to address several ecological, social, and political problems and to solve them for the greater interest of river ecosystems in general and river biodiversity in particular. One analogy can be cited to establish the distinction between environment and ecosystem which is comparable to that between house and home where the former highlights a broad canvas while the latter constitutes an integral part of the former. Ecological systems composed of three discrete elements called **structure**, **dynamics**, and **change**, are interacting within the biotic assemblages in which any two elements affect the third, resulting in ecological changes which ultimately shape the relationship between man and nature.

A number of ideas and propositions have emerged from the overall analysis on the existing conservation status of biodiversity which can be mentioned as follows:

First, to identify the threats on biodiversity, a holistic view is required on the different ecological changes which operate beyond the local territory of the species concerned.

Second, detailed analysis of socioeconomic causes are to be ascertained and which are of two broad categories: (i) overreliance on natural resources to address domestic and external pressures and (ii) the acceptance of that development model which promotes the usage of those resources.

Third, environment systems have to adequately be designed and supported in order to withstand the ongoing pressure on habitats and biodiversity.

Fourth, the root causes of biodiversity loss should not be overdetermined because of the lack of understanding of socioeconomic causes.

Fifth, the need of understanding of a very diverse source of causal factors operating at regional, national, and international levels is required in order to overcome the complications of local dynamics of resource use and biodiversity loss.

2.31 Strategies for Sustainable Biodiversity Conservation

Advances in science because of the interplay of the iterative process of induction and deduction, prediction, and testing significantly enhance scientific progress in biology and in ecology. Several anthropogenic activities during the last **15** to **20** million years have caused drastic changes in natural ecosystem of this planet even to the point of collapse, permanent loss of innumerable number of species, deterioration of water quality, disruption of natural hydrologic and chemical cycles, wastage of tons of topsoil through massive soil erosion, destruction of genetic diversity, and great sufferings of the climate of the planet. All those undesirable changes in the environment had led to cause depletion of biodiversity components which have been originated by the interactive processes in the pathways of evolution during the time span of several billion years. The science of conservation biology being a rapidly developing discipline has become more involved in complex environmental policy issues and ecosystem management by continuous infusion of different disciplines of social, physical, and life sciences.. Many attempts to conserve biodiversity hinge on concepts of community organization that need careful thought and analysis (Levins, 1992, 1998, 2005; Levine and Rees, 2002).

Besides, conservation biology is required to be molded with the economics, sociology, and politics embodying the genetic basis of conservation with an emphasis on the losses of genetic diversity, demographic processes and regulation of populations, dynamics of populations, and linking of population and landscape levels in conservation process.

These activities of human beings have been identified as the prime factors leading to cause undesirable environmental changes – deforestation, deterioration of water qualities of surface and ground water, loss of biodiversity, pollution of atmosphere and lithosphere, rapid escalation of epidemiological problems, etc. – around a century back which prompted several debates and discourses towards the initiation and consolidation of ecological thinking with the objective of solidifying several conservation efforts. Such framework is encompassing the formulation and effective application of several ecological theories, methods, and knowledge to address human-mediated environmental challenges and develop solutions to create a harmonized interaction between people and nature. Subsequently, human beings integral to the system sought to structure the viable relationship between human actions and biological responses, based on which several plans and strategies were enunciated not only to remediate the harmful effects of human actions to environment but also to facilitate decision-making processes to regulate human activities.

In a world having very apathetic mindset towards biodiversity loss and the ecological consequences of environmental degradation, dreaming for an era with the strong feeling for the well-being of the mother earth with all her natural gifts, both living and nonliving resource bases. This can only be achieved by integrating natural and social science for fulfilling the very interest for conservation which still requires additional thought to become more effective in today's human-dominated world. Accomplishing long-term sustainability in the functioning of ecosystems with required resiliency can only be possible by adhering to the basic ecological principles while continuing to meet societal needs and expectations. An integrative approach involving different disciplines can bridge gaps between manifold human dimensions of biodiversity research (population level: biological conservation, control, sustainable use, and monitoring) with the desired goals of conservation. In the context, efforts for ensuring biological conservation in the present have geared up with explicitly incorporating the concepts of both ecological integrity (maintaining the systems structure and function and the species evolutionary potential) and human dimensions (nature society values and user demands).

Out of the two million (approximately) estimated total number of species in the world (Wilson 1986), the number of endangered, economic, and damaging species hardly exceeds than a few thousands (Diamond 2002). Owing to the prevalence of only very small percentage of species that are not endangered, nor valuable or damaging, monitoring can be effectively oriented for the in-depth analysis for their bio-ecology. Establishing of a global network of long-term biodiversity monitoring with selection of suitable sites is expected to effectively contribute to the decision-making processes concerning biodiversity conservation, judicial use, and successful control.

References

Ahlstrom, E.H. 1940a. A revision of the Rotatorian genera Brachio and Platyias with description of one new species and two new varieties. *Bulletin of the American Museum of Natural History* 77: 142–184.

———. 1940b. A revision of the Rotatorian genera Brachio and Platyias with description of one new species and two new varieties. *Bulletin of the American Museum of Natural History* 77: 142–184.

Airoldi, L., and M.W. Beck. 2007. Loss, status and trends for coastal marine habitats of Europe. *Oceanography and Marine Biology: An Annual Review* 45: 345–405.

Ajithkumar, C.R., K. Remadevi, K.R. Thomas, and C.R. Biju. 1999a. Fish fauna, abundance and distribution in Chalakudy river system, Kerala. *Journal of Bombay Natural History Society* 96 (2): 244–254.

———. 1999b. Fish fauna, abundance and distribution in Chalakudy river system, Kerala. *Journal of the Bombay Natural History Society* 96 (2): 244–254.

Aller, R.C. 1988. Benthic fauna and biogeochemical processes in marine sediments: The role of burrow structures. *SCOPE (Chichester)* 33: 301–338.

Aller, R.C., and J.Y. Aller. 1998. The effect of biogenic irrigation intensity and solute exchange on diagenetic reaction rates in marine sediments. *Journal of Marine Research* 56: 905–936.

Amoros, C., and A.L. Roux. 1988. Interaction between water bodies within the floodplain of large rivers: Function and development of connectivity. *Münstersche Geographische Arbeiten* 29: 125–130.

Anderson, K.E., A. Paul, E. Mc Cauley, and L.J. Jackson. 2006. Instream flow needs in streams and rivers: The importance of understanding ecological dynamics. *Frontiers in Ecology and the Environment* 4 (6): 309–318.

Ando, A. 1999a. Waiting to be protected under the Endangered Species Act: The political economy of regulatory delay. *Journal of Law and Economics* 42: 29–60.

———. 1999b. Waiting to be protected under the Endangered Species Act: The political economy of regulatory delay. *Journal of Law and Economics* 42: 29–60.

Anon. 2010. *Water quality monitoring of five rivers viz. Shilabati, Rupnarayan, Subarnarekha, Dwarkeswar and Kansai of South West Bengal (Research project Sanctioned by West Bengal Pollution Control Board).*

———. 2011. *Water quality monitoring of five rivers viz. Shilabati, Rupnarayan, Subarnarekha, Dwarkeswar and Kansai of South West Bengal (Research project Sanctioned by West Bengal Pollution Control Board).*

Anon. 2014. Hydrobiological and geomorphological studies of Subarnarekha and Kansai river basins and their interfluves (Purulia, Bankura, Purba and Paschim Midnapore districts) with special reference to environmental management (sanctioned by West Bengal West Bengal Pollution Control Board, Kolkata, India; Principal Investigator, S.K.Chakraborty).

Arsuffi, T.L., and K. Suberkropp. 1989a. Selective feeding by shredders on leaf-colonizing stream fungi: Comparison of macroinvertebrate taxa. *Oecologia* 79: 30–37.

———. 1989b. Selective feeding by shredders on leaf-colonizing stream fungi: Comparison of macroinvertebrate taxa. *Oecologia* 79: 30–37.

Arunachalam, M., and A. Sankaranarayanan. 1999a. A new records of fishes from Gadana river, South Tamil Nadu, India. *Journal of the Bombay Natural History Society* 96: 336–337.

———. 1999b. A new records of fishes from Gadana river, South Tamil Nadu, India. *Journal of the Bombay Natural History Society* 96: 336–337.

Attwood, S.W. 1995. A demographic analysis of y-Neotricula aperta (Gastropoda: Po- matiopsidae) populations in Thailand and southern Laos, in relation to the transmission of schistosomiasis. *Journal of Molluscan Studies* 61: 29–42.

Ayala, J.R., R.B. Rader, Mc Beelk, and G.B. Schaalje. 2007a. Ground -truthing the impact of invasive species: Spatio-temporal overlap between native least chub and introduced western mosquitofish. *Biological Invasions* 9: 857–869.

Ayala, J.R., R.B. Rader, Beelk Mc, and G.B. Schaalje. 2007b. Ground -truthing the impact of invasive species: Spatio-temporal overlap between native least chub and introduced western mosquitofish. *Biological Invasions* 9: 857–869.

Azam, F., and others. 1983. The ecological role of water-column microbes in the sea. *Marine Ecology Progress Series* 10: 257–263.

Balian, E.V., H. Segers, C. Le've'que, and K. Martens. 2008. The freshwater animal diversity assessment: An overview of the results. *Hydrobiologia* 595: 627–637.

Balmford, A., A. Bruner, and P. Cooper. 2002. Ecology–economic reasons for conserving wild nature. *Science* 297: 950–953.

Balvanera, P., A.B. Pfisterer, N. Buchmann, et al. 2006. Quantifying the evidence for biodiversity effects on ecosystemfunctioning and services. *Ecology Letters* 9: 1146–1156.

Barrett, S. 1994. The biodiversity super game. *Environmental and Resource Economics* 4: 111–122.

Barrett, G.W., J.D. Peles, and E.P. Odum. 1997. Transcending processes and the levels of organisation concept. *Bioscience* 47: 531–535.

Barwick, D.H. 2004. Species richness and centrarchid abundance in littoral habitats of three southern US reservoirs. *North American Journal of Fisheries Management* 24: 76–81. Batish, 1992.

Barbier, E.B. 1992. Community-based development in Africa. In *Economics for the wilds: Wildlife, Wildlands, diversity, and development*, ed. T.M. Swanson and E. Barbier, 103–135. London: Earthscan.

Battish, S.K. 1992. *Fresh water zooplankton of India*. New Delhi: Oxford and IBH Publication.

Belsare, D.K. 1994. Inventory and status of vanishing wetland wildlife of Southeast Asia and an operational management plan for their conservation. In *Global wetlands Old World and new*, ed. W.J. Mitsch, 841–856. Amsterdam: Elsevier 7.

Berggren, M., A.K. Bergstrom, and J. Karlsson. 2015. Intraspecific autochthonous and allochthonous resource use by zooplankton in a humic lake during the transitions between winter, summer and fall. *PLoS One* 10 (3): e0120575.

Berzines, B., and B. Pejler. 1989. Rotifera occurrence in relation to temperature. *Hydrobiologia* 175: 223–231.

Berzins, B., and B. Pejler. 1989. Rotifer occurrences in relation to trophic degree. *Hydrobiologia* 182: 171–180.

Bhunia, G., P. Pradhan, G. Chanda, and S.K. Chakraborty. 2008. Comparative studies of water quality parameters and plankton production after the application of different fertilizers in cemented aquaculture tank and natural water bodies in Paschim Medinipur, West Bengal. *Zoological Research in Human Welfare*. (Published by the Zoological Society of India, Kolkata and Zoological Survey of India): Paper-45: 421–432.

Bishop, J.E. 1973. Observations on the vertical distribution of the benthos in a Malaysian stream. *Freshwater Biology* 3: 147–156.

———. 1993. *Limnology of a small Malayan River Sungai Gombak*. The Hague: Dr W. Junk, 485 pp.

Biswas, S.R. 2003. Invasive plants of Sundarbans. In *Interim report under SBCP project*. Bangladesh: IUCN, 34 pp.

Blanco, S., and E. Becarés. 2010. Are biotic indices sensitive to river toxicants? A comparison of metrics based on diatoms and macro-invertebrates. *Chemosphere* 79: 18–25.

Bolnick, D.I., R. Svanback, J.A. Fordyce, and L.H. Yang. 2003. The ecology of individuals: Incidence and implications of individual specialization. *The American Naturalist* 161 (1): 1–28.

Bootsma, H.A., and R.F. Hecky. 1993. Conservation of the African Great Lakes: A limnological perspective. *Conservation Biology* 7: 644–656.

Boggero, A., D. Fontaneto, G. Morabito, and P. Volta. 2014. Limnology in the 21st century: The importance of freshwater ecosystems as models systems in ecology and evolution. *Journal of Limnology* 73 (s1): 1–3.

Brauns, M., F. Garcia, N. Walz, and M.T. Pusch. 2007. Effects of human shoreline development on littoral macro invertebrates in lowland lakes. *Journal of Applied Ecology* 44: 1138–1144.

Brett, M.T., and C.R. Goldman. 1997. A meta-analysis of the freshwater trophic cascade. *Proceedings of the National Academy of Science USA* 93 (15): 7723–7726.

Brooks, J.L., and S.I. Dodson. 1965. Predation, body size, and competition of plankton. *Science* 150: 28–35.

Brooks, J.L. 1959. Cladocera. In *Fresh water biology*, ed. W.T. Edmondson, 587–656. New York/ London: John Wiley & Sons.

Bunn, S.E., P.M. Davies, and D.M. Kellaway. 1997. Contributions of sugar cane and invasive pasture grass to the aquatic food web of a tropical lowland stream. *Marine Freshwater Resources* 48: 173–179.

Burkepile, D.E. 2013. Comparing aquatic and terrestrial grazing ecosystems: Is the grass really green? *Oikos* 122: 306–312.

Butchart, S., M. Walpole, B. Collen, et al. 2010. Global biodiversity: Indicators of recent declines. *Science* 328: 1164–1168.

Butchart, S.H., J.P. Scharlemann, M.I. Evans, S. Quader, S. Aricò, J. Arinaitwe, et al. 2012. Protecting important sites for biodiversity contributes to meeting global conservation targets. *Plo S One* 7: e32529. https://doi.org/10.1371/journal.pone.0032529.

Cáceres, C.E., and D.A. Soluk. 2002. Blowing in the wind: A field test of overland dispersal and colonization by aquatic invertebrates. *Oecologia* 131 (3): 402–408.

Cadee, G.C. 2001. Sedimentary dynamics by bioturbating organisms. In *Ecological comparisons of sedimentary shores*, ed. K. Reise, 127–148. Berlin: Springer.

Cardinale, B.J., M.A. Palmer, C.M. Swain, S. Brooks, and N.L. Poff. 2002. The influence of substrate heterogeneity on biofilm metabolism in a stream ecosystem. *Ecology* 83: 412–422.

Cardinale, B.J., D.S. Srivastava, J.E. Duffy, et al. 2006. Effects of biodiversity on the functioning of trophic groups and ecosystems. *Nature* 443: 989–992.

Carpenter, S.R., and J.F. Kitchell. 1988. Consumer control of lake productivity. *Bio- Science* 38: 764–769.

Cathleen, W., M. Finn, S. Findlay, and D. Fischer. 2001. Submerged macrophyte effects on nutrient exchanges in riverine sediments. *Estuaries* 24: 398–406.

Celwell, A.F., R.S. Beaman, C.L. Coultas, and M.E. Lasley. 1999. *Suwannee river tidal marsh vegetation and its response to external variables and endogenous community processes*. Quincy: AF Celwell Inc.

Chakraborty, S.K. 2017. *Ecological services on intertidal benthic fauna and the sustenance of coastal wetlands along the Midnapore(East) coast, West Bengal, India* (Published in the book, Coastal Wetlands: Alteration and Remediation, Springer International Publishing AG part of Springer Nature,): 777–886.

———. 2018. Bioinvasion and environmental perturbation: Synergistic impact on coastal – Mangrove ecosystems of West Bengal, India. (Published in the book, Impacts of invasive species on coastal environments: Coast in crisis; edited by Makowski, C and Finkl, C and published by Springer International Publishing AG part of Springer, Nature): 171–245.

Chakraborty, S.K., S. Maiti Dutta, P.B. Phani Bhusan Ghosh, R. Ray, and A.K. Paul. 2014. Impact of global warming on Sundarbans mangrove ecosystem, India: Role of different assessment tools from ecosystem monitoring to molecular markers. In *Proceedings of the International conference on Green India: Strategic knowledge for combating climate change: Prospects and Challenges*, 181–200.

Chakravarty, G., S. Giri, S. Giri, and S.K. Chakraborty. 2004. Distribution of coliform bacteria in different estuaries of West Bengal Coast, India. In *Protected habitats and biodiversity*, ed. A. Kumar, J.R. Dhanze, A.K. Chopra, and D.S. Malik. (Publ. by Natcon publication), 395–402.

Chapin, F.S., E.S. Zavaleta, E.T. Eviner, et al. 2000. Consequences of changing biodiversity. *Nature* 405: 234–242.

Chatterjee, A. 2018. Waterfowl community attributes with special reference to limnological factors of three wetlands of Terai Forest, West Bengal, India. Ph. D. thesis in Zoology. The University of Burdwan, West Bengal, India, pp. 84–85.

Chakraborty, S.K. 2003. Biodiversity and conservation. In: *Perspectives and issues in environmental studies,* ed. A.D. Mukhopadhyay, (Published by the Vidyasagar University), 267–286.
Chakravarty, G., S. Giri, S. Giri, and S.K. Chakraborty. 2004. Distribution of coliform bacteria in different estuaries of West Bengal Coast, India. In: *Protected habitats and biodiversity*, ed. A. Kumar, J.R. Dhanze, A.K. Chopra and D.S. Malik (Published. by Natcon publication), 395–402.
Chan, K.M.A., A.D. Guerry, P. Balvanera, S. Klain, T. Satterfield, X. Basrto, A. Bostrom, et al. 2012. Where are cultural and social in ecosystem services ? A framework for constructive engagement. *BioScience* 62 (8): 744–756.
Chandra, A.K., G. Chakravarty, and S.K. Chakraborty. 2003. Polychaete diversity of Midnapore Coastal Belt, West Bengal, India. *Journal of Nature Conservators.* 15 (2): 95–108.
Chatterjee, S., T.K. Das, and S.K. Chakraborty. 2014. Reproductive biology and bioturbatory activities of two sympatric species of fiddler crabs *Uca lactea annulipes* and *Uca triangularis bengali* (Decopoda: Ocypodidae) at the East Midnapore Coastal belt of West Bengal, India. *Journal of Biology and Life Science* 5 (2): 106–126.
Coblentz, B.E. 1990. Exotic organisms: A dilemma for conservation biology. *Conservation Biology* 4 (3): 261–265.
Coffman, W.P., K.W. Cummins, and J.C. Wuycheck. 1971. Energy flow in a woodland stream ecosystem: I. Tissue support trophic structure of the autumnal community. *Archiv für Hydrobiologie* 68: 232–276.
Corenblit, D., A.C.W. Baas, G. Bornette, J. Darrozes, S. Delmotte, R.A. Francis, et al. 2011. Feedbacks between geomorphology and biota controlling earth surface processes and landforms: A review of foundation concepts and current understandings. *Earth-Science Reviews* 106: 307–331.
Costa, H.H. 1974. Limnology and fishery biology of the streams at Horton Plains, Sri Lanka (Ceylon). *Bulletin of the Fisheries Research Station, Sri Lanka (Ceylon)* 25: 15–26.
Costa, H.H., and E.C.M. Fernando. 1967. The food and feeding relationships of the common meso- and macrofauna in the Maha Oya, a small mountainous stream at Peradeniya, Ceylon. *Ceylon Journal of Science (Biological Sciences)* 7: 74–90.
Cottingham, K.L., B.L. Brown, and J.T. Lennon. 2001. Biodiversity may regulate the temporal variability of ecological systems. *Ecology Letters* 4: 72–85.
Cohan, F.M. 2002. What are bacterial species? *Annual Review of Microbiology* 56: 457–487.
Cohen, J.E., T. Jonsson, and S.R. Carpenter. 2003. Ecological community description using the food web, species abundance, and body size. *Proceedings of the National Academy of Sciences of the United States of America* 100: 1781–1786.
Connell, J.H. 1978. Diversity in tropical rainforests and coral reefs. *Science* 199: 1302–1310.
Connell, J.H., and R.O. Slatyer. 1977. Mechanisms of succession in natural communities and their role in community stability and organization. *American Naturalist* 111: 1119–1144.
Connell, D.W., B.M. Bycroft, G.J. Miller, and P. Lather. 1981. Effects of a barrage on flushing and water quality in the Fitzroy River estuary, Queensland. *Australian Journal of Marine and Freshwater Research* 32: 57–56.
Cottenie, K., and De Meester. 2003. Connectivity and cladoceran species richness in a mettacommunity of shallow lakes. *Freshwater Biology* 48 (5): 823–832.
Cottingham, K.L., B.L. Brown, and J.T. Lennon. 2001. Biodiversity may regulate the temporal variability of ecological systems. *Ecology Letters* 4 (1): 72–85.
Crockford, R.H., and D.P. Richardson. 2000. Partitioning of rainfall into throughfall, streamflow and interception: Effect of forest type, ground cover and climate. *Hydrological Processes* 14 (1617): 2903–2920.
Cubit, G., and G. Mountfort. 1985. *Wild India: The wildlife and scenery of India and Nepal*, 1–208. London: William Collins Sons and Co. Ltd.
Cuffney, T.F., M.R. Meador, S.D. Portor, and M.E. Gurtz. 2000. Responses of physical, chemical and biological indicators of water quality to a gradient of agricultural land use of the Yakima River basin, Washington. *Environmental Monitoring and Assessment* 64: 259–270.

Cummins, K.W. 1966. A review of stream ecology with special emphasis on organism-substrate relationships. In *Organism-substrate relationships in streams*, Special Publication No. 4, Pymatuning Symposia in Ecology, ed. K.W. Cummins, C.A. Tryon, and R.T. Hartman, 2–51. Ann Arbor: Edwards Bros.

Cummins, K.W., and M.J. Klug. 1979. Feeding ecology of stream invertebrates. *Annual Review of Ecology and Systematics* 10: 147–172.

Cummins, K.W., and J.C. Wuycheck. 1971. Caloric equivalents for investigations in ecological energetics. In *International association of theoretical and applied limnology*, vol. 18. Stuttgart: E. Schweizerbart.

Cummins, K.W., W.P. Coffman, and P.A. Roff. 1966. Trophic relationships in a small woodland stream. *Internationale Vereinigung Fur theoretische und angewandte Limnologie, Verhandlungen* 16: 627–638.

Cummins, K.W., G.W. Minshall, J.R. Sedell, C.E. Cushing, and R.C. Peterson. 1984. Stream ecosystem theory. *Internationale Vereiningung fuer Theoretische und Angewandte Limnologie Verhandlungen* 22: 1818–1827.

Cummins, K.W., M.A. Wilzbach, D.M. Gates, J.B. Perryand, and W.B. Taliaferro. 1989. Shredders and riparian vegetation. *Biocontrol Science* 39: 24–30.

Currie, D.J. 1991. Energy and large -scale patterns of animal-and plant -species richness. *The American Naturalist* 137: 27–49.

Daily, G. 1997. *Nature's services*. Washington, DC: Island Press.

Danvind, M., and C. Nilsson. 1997. Seed floating ability and distribution of alpine plants along a northern Swedish river. *Journal of Vegetation Science* 8: 271–276.

Davis, M.A., J.P. Grime, and K. Thompson. 2000. Fluctuating resources in plant communities: A general theory of invasiblity. *Journal of Ecology* 88: 528–534.

Davis, M.A., and L.B. Slobodkin. 2004. Restoration ecology: The challenge of social values and expectations. *Frontiers in Ecology* 2: 44–45.

Day. 1889. *The fauna of British India: Fishes*. London: Taylor and Francis.

DeClerck, F.A.J., J.C. Ingram, and C.M. Rumbaitis del Rio. 2006. The role of ecological theory and practice in poverty alleviation and environmental conservation. *Frontiers in Ecology and the Environment* 4: 533–540.

Declerck, S.A.J., M. Vanderstukken, A. Pals, K. Muylaert, and De Meester. 2007. Plankton diversity along a gradient of productivity and its mediation by macrophytes. *Ecology* 88: 2199–2210.

Declerck, S.A.J., J.S. Coronel, P. Legendre, and L. Brendonck. 2011. Scale dependency of processes structuring metacommunities of cladocerans in temporary pools of High-Andes wetlands. *Ecography* 34: 296–305.

Delorme, L.D. 1991. Ostracoda. In *Ecology and classification of North American invertebrates*, ed. J.H. Thrope and A.P. Covich, 691–722. San Diego: Academic Press. Inc.

Dennison, W.C., R.J. Orth, K.A. Moore, J.C. Stevenson, V. Carter, S. Kollar, P.W. Berstrom, and R.A. Batiuk. 1993. Assessing water quality with submerged aquatic vegetation. *BioScience* 43: 86–94.

De Souza Cardoso, L., de Faria, D.M., Crossetti, L.O., da Motta Marques, D., 2019. Phytoplankton, periphyton, and zooplankton patterns in the pelagic and littoral regions of a large subtropical shallow lake. *Hydrobiologia 831*(1): 119–132.

Dey, M.K., D. Pahari, A.K. Hazra, and S.K. Chakraborty. 2006. Effects of thermal power fly ash on the population structure of soil microarthropods at Kolaghat, East Midnapore District, West Bengal. *Records of the Zoological Survey of India* 106 (Part-4): 13–19.

Dhanapathi, M. V. S. S. S. 2000. *Taxonomic notes on the rotifers from India (from 1889−2000).* Publctn., 1−178. Hyderabad: Indian Association of Aquatic Biologists.

Diamond, J.M., and V.B. Serveiss. 2001. Identifying sources of stress to native aquatic fauna using a watershed ecological risk assessment. *Environmental Science & Technology* 35 (24): 4711–4718.

Díaz, S., J. Fargione, F. Chapin, and D. Tilman. 2006. Biodiversity loss threatens human well-being. *PLoS Biology* 4 (8): e277.

Doak, D.F., D. Bigger, E. Harding-Smith, M.A. Marvier, R. O'Malley, and D. Thomson. 1998. The statistical inevitability of stability–diversity relationships in community ecology. *American Naturalist* 151: 264–276.

Dodson, S.I., S.E. Arnott, and K.L. Cottingham. 2000. The relationship in lake communities between primary productivity and species richness. *Ecology* 81: 2662–2679.

Dudgeon, D. 1989. The influence of riparian vegetation on the functional organization of four Hong Kong stream communities. *Hydrobiologia* 179: 183–194.

———. 1992a. *Patterns and processes in stream ecology: A synoptic review of Hong Kong Running Waters*. Stuttgart: Schweiz. Verlagsbuchhand, 147 pp.

———. 1992b. Endangered ecosystems: A review of the conservation status of tropical Asian rivers. *Hydrobiologia* 248: 167–191.

———. 1993. The effects of spate-induced disturbance, predation and environmental complexity on macroinvertebrates in a tropical stream. *Freshwater Biology* 30: 189–197.

———. 1995a. The ecology of rivers and streams in tropical Asia. In *Ecosystems of the world 22: River and stream ecosystems*, ed. C.E. Cushing, K.W. Cummins, and G.E. Minshall, 615–657. Amsterdam: Else- vier.

———. 1995b. River regulation in southern China: Ecological implications, conservation and environmental management. *Regulated Rivers: Research Manage* 11: 35–54.

———. 2000a. Riverine wetlands and biodiversity conservation in tropical Asia. In *Biodiversity in wetlands: Assessment, function and conservation*, ed. B. Gopal, W.J. Junk, and J.A. Davis, 1–26. The Hague: Backhuys.

———. 2000b. The ecology of tropical Asian rivers and streams in relation to biodiversity conservation. *Annual Review of Ecology and Systematics* 31: 239–263.

Dudgeon, D., and G. Bretschko. 1995. Allochthonous inputs and land-water interactions in seasonal streams: Tropical Asia and temperate Europe. In *Tropical limnology, past and present*, ed. F. Schiemer, 161–179. The Hague: SPB Academic.

Dudgeon, D., and K.K.Y. Wu. 1999. Leaf litter in a tropical stream: Food or substrate for macroinvertebrates? *Archiv für Hydrobiologie* 146: 65–82.

Dudgeon, D., A.H. Arthington, M.O. Gessner, Z.I. Kawabata, D.J. Knowler, C. Leveque, R.J. Naiman, A.H. Prieur-Richard, D. Soto, M.L.J. Stiassny, and C.A. Sullilvan. 2006. Freshwater biodiversity: Importance, threats, status and conservation challenges. *Biological Reviews* 1: 63–182.

Dumont, H.J. 1983. Biogeography of rotifers. *Hydrobiologia* 104 (P): 19–30.

Dumont, H.J., and H. Segers. 1996. Estimating lacustrine zooplankton species richness and complementarity. *Hydrobiology* 341: 125–132.

Dumont, HJ., Green, J and Masundire, H 1994 *Studies on the ecology of tropical zooplankton*. Dordrecht: Development in Hydrobiology, 92, 295 p (book): n. pag. Print.

Dynesius, M., and C. Nilsson. 1994. Fragmentation and flow regulation of the river systems in the northern third of the world. *Science* 266: 753–762.

Eddy, S. 1934. A study of freshwater plankton communities. *Illinois Biological Monographs* 12 (4) 1293.7.1, 7.2.

Edmondson, W.T. 1959. Rotifera. In *Freshwater biology*, ed. W.T. Edmondson, 420–494. Wiley, New York/London.

Elena, N. Leno, Martin Solan, and Paul Bally. 2006. How diversity affects ecosystem functioning: Roles of infaunal species richness, identity and diversity in marine benthos. *Marine Ecology Progressive Series* 311: 263–271.

Elmqvist, T., C. Folke, M. Nystrom, et al. 2003. Response diversity, ecosystem change, and resilience. *Frontiers in Ecology and the Environment* 1: 488–494.

Elmqvist, T., M. Wall, and A.L. Berggren. 2001. Tropical forest reorganization after cyclone and fire disturbance in Samoa: Remnant trees as biological as biological legacies. *Conservation Ecology* 5: 10.

Elser, J.J., and C.R. Goldman. 1991. Zooplankton effects on phytoplankton in lakes of contrasting trophic status. *Limnology and Oceanography* 36: 64–90.

Elton, C.S. 1958. *The ecology of invasions by animals and plants*. London: Methuen.

Engelhardt, K.A.M., and M.E. Ritchie. 2001. Effects of macrophyte species richness on wetland ecosystem functioning and services. *Nature* 411: 687–689.

———. 2002. The effect of aquatic plant species richness on wetland ecosystem processes. *Ecology* 83: 2911–2924.

Englund, G., and J.J. Krupa. 2008. Habitat use by crayfish in stream pools: Influence of predators, depth and body size. *Freshwater Biology* 43 (1): 75–83.

Estes, J.A., J. Terborgh, J.S. Brashares, M.E. Power, J. Berger, W.J. Bond, S.R. Carpenter, T.E. Essington, R.D. Holt, J.B.C. Jackson, R.J. Marquis, L. Oksanen, T. Oksanen, R.T. Paine, E.K. Pikitch, W.J. Ripple, S.A. Sandin, M. Scheffer, T.W. Schoener, J.B. Shurin, A.R.E. Sinclair, M.E. Soule, R. Virtanen, and D.A. Wardle. 2011. Trophic downgrading of planet earth. *Science* 333: 301–306.

Evans-White, M.A., W.K. Dodds, D.G. Huggins, and D.S. Baker. 2009. Thresholds in macroinvertebrates biodiversity and stoichiometry across water-quality gradients in Central Plains (USA) streams. *Journal of the North American Benthological Society* 28 (4): 855–868.

Fagan, W.F. 2002. Connectivity, fragmentation, and extinction risk in dendritic metapopulations. *Ecology* 83: 3243–3249.

Fager, E.W. 1964. Marine sediments: Effects of a tube–building polychaete. *Science* 143: 356–359.

Findlay, Stuart E.G., and Wliiliam V. Sobczak. 2000. Microbial communities in hyporheic sediments. In *Streams and groundwater*, ed. J.B. Jones and P.J. Mulholland, 287–306. San Diego: Academic.

Findlay, Stuart E.G., Robert L. Sinsabaugh, Wliiliam V. Sobczak, and M. Hoostal. 2003. Metabolic and structural response of hyporheic microbial communities to variations in supply of dissolved organic matter. *Limnology and Oceanography* 48 (4): 1608–1617.

Fischer, J., and D.B. Lindenmayer. 2007. Landscape modification and habitat fragmentation: A synthesis. *Global Ecology and Biogeography* 16: 265–280.

Fischer, J., D.B. Lindenmayer, S.P. Blomberg, R. Montague-Drake, A. Felton, and J.A. Stein. 2007. Functional richness and relative resilience of bird communities in regions with different land use intensities. *Ecosystems* 10: 964–974.

Fontaneto, D., W.H. De Smet, and C. Ricci. 2006. Rotifers in saltwater environments, re-evaluation of an inconspicuous taxon. *Journal of Marine Biological Association of the United Kingdom* 86: 623–656.

Fontaneto, D., E.A. Herniou, C. Boschetti, M. Caprioli, G. Melone, C. Ricci, and T.G. Barraclough. 2007. Evidence for independently evolving species in bdelloid rotifers. *PLoS Biology* 5: 914–921.

Fretwell, S.D. 1977. The regulation of plant communities by food chains exploiting them. *Perspectives in Biology and Medicine* 20: 169–185.

Frost, N.M., M.T. Burrows, M.P. Johnson, M.E. Hanley, and S.J. Hawkins. 2005. Measuring surface complexity in ecological studies. *Limnology and Oceanography: Methods* 3: 203–210.

Fischlin, A., G. Midgley, J. Price, et al. 2007. Ecosystems, their properties, goods, and services. In *Climate Change 2007: Impacts, adaptation and vulnerability. Working group II contribution to the Intergovernmental Panel on Climate Change fourth assessment report*, ed. IPCC, vol. 7, 777–792. Cambridge. Fish. Ecosystems: Cambridge University Press.

Fonseca, C.R., and G. Ganade. 2001. Species functional redundancy, random extinctions and the stability of ecosystems. *Journal of Ecology* 89: 118–125.

Foose, T.J., and N. van Strien. 1997. *Asian rhinos-status survey and conservation action plan*. Cambridge: World Conservation Monitoring Centre, 112 pp.

Frost, N.M., M.T. Burrows, M.P. Johnson, M.E. Hanley, and S.J. Hawkins. 2005. Measuring surface complexity in ecological studies. *Limnology and Oceanography: Methods* 3: 203–210.

Fullerton, A.H., K.M. Burnett, E.A. Steel, R.L. Flitcroft, G.R. Pess, B.E. Feist, C.E. Torgersen, D.J. Miller, and B.L. Sanderson. 2010. Hydrological connectivity for riverine fish: Measurement challenges and research opportunities. *Freshwater Biology* 55: 2215–2237.

Gelwick, F.P., and W.J. Matthews. 1992. Effects of an algivorous minnow on temperate stream ecosystem properties. *Ecology* 73: 1630–1645.

Ghetti, P.F., and O. Ravera. 1994. European perspective in biological monitoring. In *Biological monitoring of aquatic systems*, ed. S.L. Loeb and A. Space, 31–46. Boca Raton: CRC.

Gilbert, J., and D.C. Culver. 2009. Assessing and conserving groundwater biodiversity: an Introduction. *Freshwater Biology* 54: 1163–1177.

Giri, S., P. Pradhan, and S.K. Chakraborty. 2008. Studies on hydrobiological status of Kansai and Dwarkeswar river in West Bengal, India. *Journal of Indian Fisheries Society of India* 40 (1): 59–64.

Gliwicz, Z.M., and J. Pijanowska. 1989. The role of predation in zooplankton succession. In *Plankton ecology*, 253–296.

Gooderham, J.P.R., L.A. Barmuta, and J.A. Davies. 2007. Upstream hereogenous zones: Small stream systems structured by a lack of competence ? *Journal of the North American Benthological Society* 26 (3): 365–374.

Gray, J.S., and M. Elliot. 2009. *Ecology of marine sediments: From science to management*. Oxford: Oxford University Press.

Greenberg, A.E. 1964. Plankton of the Sacramento River. *Ecology* 5: 40–49.

Gross, M. 2003. *Inventing nature: Ecological restoration by public experiments*. Oxford: Lexington Books.

Gurnell, A.M., and G.E. Petts. 2002. Island-dominated landscapes of large floodplain rivers, a European perspective. *Freshwater Biology* 47: 581–600.

Gurnell, A.M., C.R. Hupp, and S.V. Gregory. 2000. Linking hydrology and ecology. *Hydrological Processes* 14: 2813–2815.

Gurney, R. 1933. *British fresh water copepoda. III. The classification of the Cyclopoida and the parasitic forms derived from them*, 1–384. London: Ray Society.

Gibert, J., D.L. Danielopol, and J.A. Stanford. 1994. *Groundwater ecology*. San Diego: Academic, 571 p.

Gilbert, F., A. Gonzalez, and I. Evans-Freke. 1998. Corridors maintain species richness in the fragmented landscapes of a microecosystem. *Proceedings of the Royal Society of London B* 265: 577–582.

Glowka, L., F. Burhenne-Guilmin, and H. Synge. 1994. *A guide to the convention on biological diversity*. Gland: IUCN.

Greenberg, A.E., R.R. Trussell, L.S. Clesceri, and M.A.H. Franson, eds. 1985. *Standard methods for the examination of water and wastewater*. Washington, DC: American Public Health Association.

Griffin, J.K., Hayekidl, S.T. Howkins, R.C. Thomson, and S.R. Jenkins. 2018. Predator diversity and ecosystem functioning: Density modifies the effect of resource partitioning. *Ecology* 89: 298–305.

Gunter, G. 1961. Some relations of estuarine organisms to salinity. *Limnology and Oceanography* 6: 182–190.

Gurnell, A. 2012. Fluvial geomorphology: Wood and river landscapes. *Nature Geoscience* 5 (2): 93–94.

Gurevitch, J., L.L. Morrow, A. Wallace, and J.S. Walsh. 1992. A meta-analysis of competition in field experiments. *The American Naturalist* 140: 539–572.

Gregory, S.V., F.J. Swanson, W.A. Mckee, and K.W. Cummins. 1991. An ecosystem perspective of riparian zones. *Bio Science* 41: 540–551.

Hagen, M., W.D. Kissling, C. Rasmussen, M.A.M. De Aguiar, L.E. Brown, D.W. Carstensen, I. Alves-Dos-Santos, Y.L. Dupont, F.K. Edwards, J. Genini, P.R. Guimaraes, G.B. Jenkins, P. Jordano, C.N. Kaiser-Bunbury, M.E. Ledger, K.P. Maia, F.M.D. Marquitti, O. Mclaughlin, L.P.C. Morellato, E.J. O'Gorman, K. Trøjelsgaard, J.M. Tylianakis, M.M. Vidal, G. Woodward, and J.M. Olesen. 2012. *Biodiversity*, Species interactions and ecological networks in a fragmented world advances in ecological research, 89–210. New York: Elsevier.

Hairston, N.G., F.E. Smith, and L.B. Slobodkin. 1960. Community structure, population control, and competition. *American Naturalist* 94: 421–425.

Halder Mallick, P., and S.K. Chakraborty. 2014. Biotic interactions of freshwater zooplankton community vis-à-vis climate change. In *Proceedings of the international conference on Green India: Strategic knowledge for combating climate change: Prospects and challenge*, 214–229.

———. 2015. Does intra-site connectivity influence the dynamics of zooplankton metacommunity in fhresh water habitats ? *Turkish Journal of Fisheries and Aquatic Sciences* 15: 661–675.

———. 2016. *Does intra-site connectivity influence the dynamics of zooplankton metacommunity in freshwater habitats?* Turkey: (CFRI) Trabzon.

Halder, P., G. Bhunia, P. Pradhan, S. Banerjee, and S.K. Chakraborty. 2007. Ecological gradients determining the diversity of Zooplanktons in the wetlands in lateritic tracts of South-West Bengal. *Zoological Research in Human Welfare* Paper-5: 37–46.

Halder Mallick, P., P.K. Jana, S.K. Chakraborty, and S. Banerjee. 2013. Relative tolerance of some tropical freshwater microcrustaceans to acidification. *Turkish Journal of Zoology* 37: 228–237.

Handoo, J.K., N. Saraf, and V. Kaul. 1988. Energy content and ecological efficiency of macrophytes in Dal lake, Kashmir. *Archiv fur Hydrobiologie* 111: 351–367.

Hanson, R.T. 1998. Paleoclimatic analyses for historical and future simulations of ground water/ surface water flow in the Santa Clara-Calleguas Basin, Ventura County, California. In *Proceedings of 15th Annual Pacific Climate (PACLIM) Workshop*, Technical Report 64 of the Interagency Ecological Program for the Sacramento-San Joaquin Estuary. 15th Annual PACLIM Conference, 133. American Geophysical Union.

Hansson, L.J., and B. Norrman. 1995. Release of dissolved organic carbon(DOC) by the scyphozoan jellyfish Aurelia aurita and its potential influence on the production of planktonic bacteria. *Marine Biology* 121: 527–532.

Hansson, L.A., L. Lundqvist, and L. Drake. 2000. Diversified use of water resources (In Swedish with english summary). *Vatten* 56: 115–117.

Hansson, L., C. Bronmark, A. Nilsson, and K. Abjornsson. 2005. Conflicting demands on wetland ecosystem services: Nutrient retention, Biodiversity or both ? *Freshwater Biology* 50 (4): 705–714.

Harris, G.P., and A.L. Heathwaite. 2005. Inadmissible evidence: Knowledge and prediction in land and riverscapes. *Journal of Hydrology* 304 (1−4): 3–19.

Harshey, A.E., G. Gettel, M.E. McDonald, M.C. Miller, H. Mooers, W.J. O'Brien, J. Pastor, C. Richards, and J.A. Schuldt. 1999. A geomorphic -trophic model for landscape control of trophic structure in arctic lakes. *Biocontrol Science* 49: 887–897.

Hart, D.D., and C.M. Finelli. 1999. Physical-biological coupling in streams: The pervasive effects of flow on benthic organisms. *Annual Review of Ecology and Systematics* 30: 363–395.

Hawkes, H.A. 1975. River zonation and classification. In *River ecology*, ed. B.A. Whitton, 312–374. Oxford: Blackwell Science Publishers.

Hazelwood, D.H., and R.A. Parker. 1961. Population dynamics of some fresh water zooplankton. *Journal of Ecology* 42: 266–274.

Hershey, A.E., A. Lamberti, and R.M. Northington. 2009. Aquatic insect ecology. In *Ecology and classification of North American freshwater invertebrates*, ed. J.H. Throp and A.P. Covich, 3rd ed., 659–693. San Diego: Academic Press.

Hillebrand, H. 2004. On the generality of the latitudinal diversity gradient. *The American Naturalist* 163: 192–211.

Hilsenhoff, W.L. 1988. Rapid field assessment of organic pollution with a family-level biotic index. *Journal of the North American Benthological Society* 7: 65–68.

Hobbs, R.J., and S.E. Humphries. 1995. An integrated approach to the ecology and management of plant invasions. *Conservation Biology* 9 (4): 761–770.

Hoeinghaus, D.J., A.A. Agostinho, L.C. Gomea, F.M. Pelicice, E.K. Okada, J.D. Latini, E.A. Kashiwaqui, and K.O. Winemiller. 2009. Effects of river impoundment on ecosystem services of large tropical rivers: Embodied energy and market value of artisanal fisheries. *Conservation Biology* 23: 1222–1231.

Hofmann, W. 1977. The influence of abiotic environmental factors on population dynamics in planktonic rotifers. *Arch Hydrobiol Beih Ergebn Limnol* 8: 77–83.

Hooper, D.J., F.S. Chapin, et al. 2005. Effects of biodiversity on ecosystem functioning: A consensus of current knowledge. *Ecological Monographs* 75: 3–35.

Hortle, K. 2007. *Consumption and yield of fish and other aquatic animals from the lower Mekong basin*, MRC technical paper no. 16. Vientiane, Lao PDR: Mekong River Commission, 87 pp.

Hortal, J., J.M. Lobo, Jim Ismael, A. Amany, and Mohamed M. Dorgham. 2003. Ecological indices as a tool for assessing pollution in Ei-Dekhaila Harbour (Alexandria, Egypt). *Oceanologia* 45 (1): 121–131.

Hortal, J., J.M. Lobo, and A. Jimenez-Valverde. 2012. Basic questions in biogeography and the (lack of) simplicity of species distributions: Putting species distribution models in the right place. *Natureza e Conservacao.* 10: 108–118.

Hughes R.M. 1995. Defining acceptable conditions. Biological assessment criteria: Tools for water resource planning and decision-making (Eds W.S. Davis and T. Simon), pp. 31±47. Lewis publishers, Boca Raton.

Hughes, M.H., and P.W. Parmalee. 1999. Prehistoric and modern fresh water mussel(mollusca: bivalvia: unionoidea) faunas of the Tennessee River: Albama, Kentucky, and Tennessee. *Regulated Rivers: Research and Management* 15 (1–3): 25–42.

Hughes, J.B., and O.L. Petchey. 2001. Merging perspectives on biodiversity and ecosystem functioning. *Trends in Ecology and Evolution* 16: 222–223.

Hughes, J.B., R. Anthony, A.R. Ives, and J. Norberg. 2002. Do species interactions buffer environmental variation (in theory) ? In *Biodiversity and ecosystem functioning*, ed. M. Loreau et al., 92–101. Oxford: Oxford University Press.

Hupp, C.R. 1999. Fluvial geomorphic processes, water quality and nutrients of bottomland hardwood systems. In *Ecology and management of bottomland hardwood systems, the state of our understanding*, ed. L. Frederickson, R. Kamiski, and S.L. King. Mississipi: Mississipi State University Press, U.S.A.

Hupp, C.R., and W.R. Osterkamp. 1996. Riparian vegetation and fluvial geomorphic processes. *Geomorphology* 14: 277–295.

Hupp, C.R., W.R. Osterkamp, and A.D. Howard. 1995. *Biogeomorphology -terrestrial and fresh water systems*. Amsterdam: Elsevier Science.

Hutchinson, G.E. 1967. *A treatise on limnology. Ll introduction to lake biology and the limnoplankton*. Vol. 7, 1–31. New York: Wiley.

———. 1969. *Eutrophication, past and present*. Washington, DC: Eutrophication- Proceedings of a Symposium. Nat. Acad. Sei, 661 p.

Hynes, H.B.N. 1970. *The ecology of running waters*. Toronto: University of Toronto Press, 555 pp.

ICOLD (International Commission on Large Dams). 2016. Available http://www.icold-cigb.org/GB/World_register/general_synthesis.asp

Irons, J.G., M.W. Oswood, R.J. Stout, and C.M. Pringle. 1994. Latitudinal patterns in leaf lit- ter breakdown: Is temperature really important? *Freshwater Biology* 32: 401–411.

Ismail, M.Z. 1994. Zoogeography and biodiversity of the freshwater fishes of Southeast Asia. *Hydrobiologia* 285: 41–48.

IUCN. 2004. *Red list of threatened species: A global species assessment* (eds. Baillie J, Hilton–Taylor C, Stuart SN).

IUCN (International Union for the Conservation of Nature). 2000. *Vision for water and nature: A world strategy for conservation and sustainable management of water resources in the 21st century*. Gland/Cambridge: International Union for the Conservation of Nature.

Jackson, C.R., P.F. Churchill, and E.E. Roden. 2001. Successional changes in bacterial assemblage structure during epilithic biofilm development. *Ecology* 82: 555–566.

Jayaram, K.C. 1999. *The freshwater fishes of the Indian region*. Delhi: Narendra Publishing House.

Jenkins, D. G., 2014. Lakes and rivers as microcosms, version 2.0 . Journal of Limnology \(s1): 20–32. Joniak et al. (2007).

Jungwirth, M., G. Haidvogl, O. Moog, S. Muhar, and S. Schmutz. 2003. *Angewandte Fischökologie and Fließgewässern*. Wien: Facultas Universitätsverlag.

Joniak, T., N. Kuczynska-Kippen, and M. Gabka. 2017. Effect of agricultural landscape characteristics on the hydrobiota structure in small water bodies. *Hydrobiologia* 793: 121–133.

Joshi, K.D., Md.A. Alam, D.N. Jha, and K. Srivastava. 2017. Studies on ecology, fish diversity and fisheries of Ken-Betwa rivers (India): Proposed for interlinking. *Aquatic Ecosystem Health and Management* 20 (1-2): 71–85.

Kattge, J., S. Diaz, S. Lavorel, et al. 2011. TRY – A global database of plant traits. *Global Change Biology* 17: 2905–2935.

Kaul, V., and J.K. Handoo. 1993. Ecology and management of some typical wetlands of Kashmir. In *Ecology and pollution of Indian lakes and reservoirs*, ed. P.C. Mishra and R.K. Trivedy, 112–130. New Delhi: Ashish Publishing House.

Kaul, V., and A.K. Pandit. 1982. Biotic factors and food chain structure in some typical wetlands of Kashmir. *Journal of Pollution Research* 1 (1–2): 49–54.

Kaul, V., D.N. Fotedar, A.K. Pandit, and C.L. Trisal. 1978. A comparative study of plankton population of some typical fresh water bodies of Jammu and Kashmir state. In *Environmental physiology and ecology pf plants*, ed. D.N. Sen and R.P. Bansal, 249–269. Dehra Dun: Singh, B, Pal Singh M.

Kaya, Z., and D.J. Raynal. 2001a. Biodiversity and conservation of Turkish forests. *Biological Conservation* 97: 131–141.

Kennedy, T.L., and T.F. Turner. 2011. River channelization reduces nutrient flow and macroinvertebrate diversity at the aquatic terrestrial transition zone. *Ecosphere* 2 (art35). https://doi.org/10.1890/ES11-00047.1.

———. 2001b. Biodiversity and conservation of Turkish forests. *Biological Conservation* 97: 131–141.

Kenworthy, W.J., and D.E. Haunert. 1991. *The light requirements of seagrasses: Proceedings of a workshop to examine the capability of water quality criteria, standards and monitoring programs to protect seagrasses*, NOAA Tech. Memorandum NMFS-SEFC-287. Beaufort: U.S. National Marine Fisheries Service.

Kerner, M., P. Hohenberg, E. Siegmund, R. Marcus, and S. Alejandro. 2003. Self organization of dissolved organic matter to micelle-like microparticles in river water. *Nature* 422: 150–154.

Kiffney, P.M., J.S. Richardson, and J.P. Bull. 2003. Responses of periphyton and insects to experimental manipulation of riparian buffer width along forest streams. *Journal of Applied Ecology* 40: 1060–1076.

Kinlan, Brian P., and Steven D. Gaines. 2003. Propagule dispersal in marine and terrestrial environments: A community perspective. *Ecology* 84 (8): 2007–2020.

Klein, A.M., I. Steffan-Dewenter, and T. Tscharntke. 2003. Fruit set of highland coffee increases with the diversity of pollinating bees. *Proceedings of the Royal Society, Series B* 270: 955–961.

Kobayashi, S.D., N. Malachowa, and F.R. Deleo. 2015. Pathogenesis of Staphylococcus aureus abscesses. *The American Journal of Pathology* 185 (6): 1518–1527.

Kobyashi, T., T.J. Ralph, D.S. Ryder, S.J. Hunter, R.J. Shiel, and H. Segers. 2015. Spatial dissimilarities in plankton structure and function during flood pulses in a semi-arid floodplain wetland system. *Hydrobiologia* 747: 19–31.

Kottelat, M. 1989. Zoogeography of the fishes from Indochinese inland waters with an annotated checklist. *Bulletin of the British Museum University Amsterdam* 12: 1–56.

Krebs, C.J. 1972. *Ecology: The experimental analysis of distribution and abundance*. New York: Harper & Row.

Kremen, C., N.M. Williams, and R.W. Thorp. 2002. Crop pollination from native bees at risk from agricultural intensification. *Proceedings of the National Academy of Sciences of the United States of America* 99: 16812–16816.

Kremen, C., N.M. Williams, R.L. Bugg, J.P. Fay, and R.W. Thorp. 2004. The area requirements of an ecosystem service: Crop pollination by native bee communities in California. *Ecology Letters* 7: 1109–1119.

Krueger, C.C., and T.F. Waters. 1983. Annual production of macroinvertebrates in three streams of different water quality. *Ecology* 64: 840.

Lambrions, J.G. 2002. The variable invasive success of Cortaderia species in a complex landscape. *Ecology* 83: 518–529.

Lamberti, G.A., and J.W. Moore. 1984. Aquatic insects as primary consumers. In *The ecology of aquatic insects*, ed. V.H. Resh and D.M. Rosenberg, 164–195. New York: Praeger.

Lancaster, J., and A. Mole. 1999. Interactive effects of near- bed flow and substratum texture on the micro-distribution of lotic macro-invertebrates. *Archiv Fur Hydrobiologie* 146: 83–100.

Lancaster, J., B.J. Downes, and A. Arnold. 2010. Environmental constraints on oviposition limit egg supply of a stream insect at multiple scales. *Oecologia* 163: 373–384.

Lavorel, S., and E. Garnier. 2002. Predicting changes in community composition and ecosystem functioning from plant traits: Revisiting the holy grail. *Functional Ecology* 16: 545–556.

Lawrence, J.R., and D.E. Caldwell. 1987. Behavior of bacterial stream populations within the hydrodynamic boundary layers of surface microenvironments. *Microbial Ecology* 14: 15–27.

Leibold, M.A., M. Holyoak, N. Mouquet, P. Amarasekare, J.M. Chase, M.F. Hoopes, R.D. Holt, J. B. Shurin, R. Law, D. Tilman, M. Loreau, and A. Gonzalez. 2004. The metacommunity concept: A framework for multi-scale community ecology. *Ecology Letters* 7: 601–613.

Leopold, L.B., M.G. Wolman, and J.P. Miller. 1964. *Fluvial processes in geomorphology*. San Francisco: W. H. Freeman and Co.. 522 pp.

Levin, S.A. 1992. The problem of pattern and scale in ecology. *Ecology* 73: 1943–1967.

———. 1998. Ecosystems and the biosphere as complex adaptive systems. *Ecosystems* 1: 431–436.

———. 2005. Self-organization and the emergence of complexity in ecological systems. *Biocontrol Science* 55 (12): 1075–1079.

Logue, J.B., N. Mouquet, H. Peter, and H. Hillebrand. 2011. Empirical approaches to metacommunities: A review and comparison with theory. *Trends in Ecology & Evolution* 26: 482–491.

Loreau, M., S. Naeem, P. Inchausti, J. Bengtsson, J.P. Grime, A. Hector, D.U. Hooper, M.A. Huston, D. Raffaelli, B. Schmid, D. Tilman, and D.A. Wardle. 2001. Biodiversity and ecosystem functioning: Current knowledge and future challenges. *Science* 294: 804–808.

Loreau, M., A. Downing, M. Emmerson, and A. Gonzalez. 2002. A new look at the relationship between diversity and stability. In *Biodiversity and ecosystem functioning: Synthesis and perspectives*, ed. M. Loreau, S. Naeem, and P. Inchausti, 79–91. Oxford: Oxford University Press.

MacArthur, R.H. 1967. *The theory of island biogeography*. Princeton: Princeton University Press.

Madhyastha, M.N., and S. Murugan. 1996. Ichthyofauna of the sector of Kaveri River in head region. In *Advance in fish and wildlife ecology and biology*, ed. B.L. Kaul, 1–332. Delhi: Daya Publishing House.

Madsen, J.D., P.A. Chambers, W.F. James, E.W. Koch, and D.F. Westlake. 2001. The interaction between water movement, sediment dynamics and submersed macrophytes. *Hydrobiologia* 444: 71–84.

Malanson, G.P. 1993. *Riparian landscapes*, Cambridge studies in ecology, 1–296. Cambridge University Press.

Mallick, P.H., and S.K. Chakraborty. 2018. Forest, wetland and biodiversity: Revealing multi-faceted ecological services from ecorestoration of a degraded tropical landscape. *Ecohydrology and Hydrobiology* 18 (3): 278–296.

Margalef, R. 1983. *Limnologia*. Barcelona: Omega.

McAuliffe, J.R. 1984. Resource depression by a stream herbivore: Effects of distributions and abundances of other grazers. *Oikos* 42: 327–333.

McLachlan, A., and A.C. Brown. 2006. *The ecology of sandy shores*, 1–373. Burlington: Academic.

McNaughton, S.J. 1977. Diversity and stability of ecological communities: A comment on the role of empiricism in ecology. *American Naturalist* 111: 515–525.

Mepf, H.M. 1999. Drug, turbulence and diffusion in flow through emergent vegetation. *Water Resources Research* 35: 479–489.

Merritt, D.M., and E.E. Wohl. 2006. Plant dispersal along rivers hydraulics, hydrology and dispersal phenology. *Ecological Applications* 12: 1071–1087.

Meyer, J.L. 1996. Conserving ecosystem function. In *The ecological basis of conservation: Heterogeneity, ecosystems, and biodiversity*, ed. T.A. Pickett, R.S. Ostfield, M. Shachak, and G.E. Likens, 136–145. New York: Chapman and Hall.

Michael, R.G. 1968. Studies on the zooplankton of a tropical fish pond. *Hydrobiologia* 32: 47–68.

Michels, E., K. Cottenie, L. Neys, and L. De Meester. 2001. Zooplankton on the move: First results on the quantification of dispersal of zooplankton in a set of interconnected ponds. *Hydrobiologia* 442: 117–126.

Midya, S., R.K. Ganguly, S.K. Saruk Islam, and S K Chakraborty∗. 2019. Attachment and antimicrobial susceptibility of bacterial associates of zooplanktonic copepod: Lesson for environmental safety. *Ecotoxicology and Environmental Safety* 180: 749–755.

Midya, S., S.K.S. Islam, R. Paul, and S.K. Chakraborty. 2019. Attachment and antimicrobial susceptibility of bacterial associates of zooplanktonic copepod: Lesson for environmental safety. *Ecotoxicology and Environmental Safety* 180: 749–755.

Millennium Ecosystem Assessment. 2005. *Ecosystems and human well-being: Wetlands and water synthesis*. Washington, DC: World Resources Institute.

Minshall, G.W., R.C. Peterson, K.W. Cummins, T.L. Bott, J.R. Sedell, C.E. Cushing, and R.L. Vannote. 1983. Interbiome comparison of stream ecosystem dynamics. *Ecological Monographs* 53: 1–25.

Minshall, G.W., K.W. Cummins, R.C. Petersen, C.E. Cushing, D.A. Bruns, J.R. Sedell, and R.L. Vannote. 1985. Developments in stream ecosystem theory. *Canadian Journal of Fisheries and Aquatic Sciences* 42: 1045–1055.

Miracle, M.R. 1974. Niche structure in freshwater zooplankton: A principal components approach. *Ecology* 55: 1306–1316.

Mishra, S.S., P. Pradhan, S.K. Chakraborty, and R.K. Bhakat. 2003. Plants used for stupefying fish in Southern West Bengal. *Science and Culture* 69 (1–2): 87–89.

Mishra, S.S., S.K. Acharjee, and S.K. Chakraborty. 2009. Development of tools for assessing conservation categories of siluroid fishes of fresh water and brackish water wetlands of South West Bengal, India. *Journal of Environmental Biology of Fishes* 84: 395–407.

Mitsch, W.J., and J.G. Gosselink. 1986. *Wetlands*. New York: Van Nostrand Reinhold.

———. 1993. *Wetlands*. 2nd ed. New York: Van Nostrand Reinhold.

Moilanen, A., and A. Arponea. 2011. Administrative regions in conservation: Balancing local priorities with regional to global preferences in spatial planning. *Biological Conservation* 144 (5): 1719–1725.

Moller, E.F. 2005. Sloppy feeding in marine copepods: Prey-size-dependent production of dissolved organic carbon. *Journal of Plankton Research* 17: 27–35.

Mosisch, T.D., and S.E. Bunn. 1997. Temporal patterns of rainforest stream epilithic algae in relation to flow-related disturbance. *Aquatic Botany* 58: 181–193.

Motta, R.L., and V.S. Uieda. 2005. Food web structure in a tropical stream ecosystem. *Austral Ecology* 30: 58–73.

Myers, N. 1996. Environmental service of biodiversity. *Proceedings of the National Academy of Sciences of the United States of America* 93: 2764–2769.

Naeem, S. 2002. Disentangling the impacts of diversity on ecosystem functioning in combinatorial experiments. *Ecology* 83: 2925–2935.

Naeem, S. 2002a. Ecosystem consequences of biodiversity loss: The evolution of a paradigm. *Ecology* 83: 1537–1552.

———. 2002. Ecosystem consequences of biodiversity loss: The evolution of a paradigm. *Ecology* 83: 1537–1552.

Naeem, S., and S. Li. 1997a. Biodiversity enhances ecosystem reliability. *Nature* 390: 507–509.

———. 1997b. Biodiversity enhances ecosystem reliability. *Nature* 390: 507–509.

Naeem, S., and J.P. Wright. 2003. Disentangling biodiversity effects on ecosystem functioning: Deriving solutions to a seemingly insurmountable problem. *Ecology Letters* 6: 567–579.

Naeem, S., M. Loreau, and P. Inchausti. 2002. Biodiversity and ecosystem functioning: The emergence of a synthetic ecological framework. In *Biodiversity and ecosystem functioning: Synthesis and perspectives*, ed. M. Loreau, S. Naeem, and P. Inchausti. Oxford: Oxford University Press.

Naiman, R.J. 1997. Large animals and system-level characteristics in river corridors. *Bioscience* 47: 521–529.

Naiman, R.J., J.M. Melillo, and J.E. Hobbie. 1986. Ecosystem alteration for boreal forest streams by beaver (Castor canadensis). *Ecology* 67: 1254–1269.

Naiman, R.J., J.M. Melilo, M.A. Lock, T.E. Ford, and S.R. Reice. 1987. Longitudinal patterns of ecosystem processes and community structure in a subarctic river continuum. *Ecology* 68: 1139–1156.

Naiman, R.J., H. Decamps, and M.E. McClain. 2005. *Riparia: ecology, conservation, and management of streamside communities*. San Diego: Elsevier, 430 p.

Natarajan, A.V. 1989. Environmental impact of Ganga Basin development on gene-pool and fisheries of the Ganga River system. *Canadian Special Publication of Fisheries and Aquatic Sciences* 106: 545–560.

Nayar, C.K.G. 1970. Studies on the rotifer population of two ponds at Pilani, Rajasthan. *Journal of the Zoological Society of India* 22: 168–185.

Neves, I.F., O. Rocha, K.F. Roche, and A.A. Pinto. 2003a. Zooplankton community structure of two marginal lakes of the river Cuiaba (Mato Grasso, Brazil) with analysis of rotifera and cladocera diversity. *Brazilian Journal of Biology* 63 (2): 329–403.

———. 2003b. Zooplankton community structure of two marginal lakes of the river Cuiaba (Mato Grasso, Brazil) with analysis of rotifera and cladocera diversity. *Brazilian Journal of Biology* 63 (2): 329–403.

Newbold, J.D., J.W. Elwood, and R.V. O'Neill. 1981. Measuring nutrient spiraling in streams. *Canadian Journal of Fisheries and Aquatic Sciences* 38: 860–863.

Newbold, J.D., R.V. O'Neill, J.W. Elwood, and W. Van Winkle. 1982a. Nutrient spiraling in streams: implications for nutrient and invertebrate activity. *American Naturalist* 120: 628–652.

———. 1982b. Nutrient spiraling in streams: Implications for nutrient and invertebrate activity. *American Naturalist* 120: 628–652.

Nilsson, C., G. Grelsson, M. Johansson, and U. Sperens. 1989. Patterns of plant species richness along riverbanks. *Ecology* 70: 77–84.

Nilsson, C., A. Ekblad, M. Gardfjell, and B. Carlberg. 1991a. Long-term effects of river regulation on river margin vegetation. *Journal of Applied Ecology* 28: 963–987.

———. 1991b. Long-term effects of river regulation on river margin vegetation. *Journal of Applied Ecology* 28: 963–987.

———. Gardfjell, and G. Grelsson. 1991b. Importance of hydrochory in structuring plant communities along rivers. *Canadian Journal of Botany* 69: 2631–2633.

Nilsson, C., R. Jannson, and U. Zinko. 1997. Long-term responses of river-margin vegetation to water-level regulation. *Science* 276: 798–800.

Nilsson, C., C.A. Reidy, M. Dynesius, and C. Revenga. 2005. Fragmentation and flow regulation of the world's large river systems. *Science* 308: 405–408.

Nolen, J.A., and R.G. Pearson. 1993. Factors affecting litter processing by Anisocentro-pus kirramus (Trichoptera: Calamoceratidae) from an Australian tropical rainforest stream. *Freshwater Biology* 29: 469–479.

Nogardy, T., R. Pourriot, and H. Segers. 1995. *Rotifera. Vol. 3: The Notommatidae and The Scaridiidae*, 1–248. Amsterdam: SPB Academic Publishing.

Noss, R.F. 1990. Indicators for monitoring biodiversity: A hierarchical approach. *Conservation Biology* 4: 355–364.

Ormerod, S.J. 2003. Restoration in applied ecology: editor's introduction. *Journal of Applied Ecology* 40: 44–50.

———. 2004. A golden age of river restoration science? *Aquatic Conservation: Marine and Freshwater Ecosystems* 14: 543–549.

Osterkamp, W.R. 1980. Sediment -morphology relations of alluvial channels. Proceedings of the Symposium on Watershed of very large rivers? In *Proceedings of the International Large River Symposium (LARS)*, Canadian special publication on fisheries and aquatic sciences. No. 106, ed. D.P. Dodge, 49–55.

Osterkamp, W.R., and C.P. Hupp. 2010. Fluvial processes and vegetation -glimpses of the past, the present and perhaps the future. *Geomorphology* 116 (3–4): 274–285.

Osterkamp, W.R., and C. Hupp. 2012. Fluvial processes and vegetation – Glimpses of the past, the present and perhaps the future. *Geomorphology* 116 (3–4): 274–285.

Ormerod, S.J., S.D. Rundle, S.M. Wilkinson, G.P. Daly, K.M. Dale, and I. Juttner. 1994. Altitudinal trends in the diatoms, bryophytes, macroinvertebrates and fish of a Nepalese river system. *Freshwater Biology* 32: 309–322.

Paetzold, A., C.J. Schubert, and K. Tockner. 2005. Aquatic-terrestrial linkages along a braided river. Riparian arthropods feeding on aquatic insects. Ecosystems

———. 2005. Aquatic-terrestrial linkages along a braided river. Riparian arthropods feeding on aquatic insects. *Ecosystems* 8: 748–759.

Paetzold, A., J.F. Bernet, and K. Tockner. 2006a. Consumer -specific responses to riverine subsidy pulses in a riparian arthropod assemblage. *Freshwater Biology* 51: 1103–1115.

———. 2006b. Consumer -specific responses to riverine subsidy pulses in a riparian arthropod assemblage. *Freshwater Biology* 51: 1103–1115.

Pakhira, H., and S.K. Chakraborty. 2016a. Diversity and distribution of Molluscs in Subarnarekha River, India with emphasis on identifying indicator species. *International Journal of Current Research* 8 (11): 42162–42164.

———. 2016b. Diversity and distribution of Molluscs in Subarnarekha River, India with emphasis on identifying indicator species. *International Journal of Current Research* 8 (11): 42162–42164.

———. 2018a. Community structure of benthic mollusks in contrasting ecozones of a transboundary river in India: An ecological interpretation. *International Journal of Life Sciences Research* 6 (3): 233–238.

———. 2018b. Community structure of benthic mollusks in contrasting ecozones of a transboundary river in India: An ecological interpretation. *International Journal of Life Sciences Research* 6 (3): 233–238.

Palmer, M.A. and Lake, P.S. 2001. Invertebrates, Freshwater, Overview Encyclopodia of biodiversity. Academic Press, New York: 531–542.

Palmer, M.A., E.S. Bernhardt, J.D. Allan, et al. 2005. Standards for ecologically successful river restoration. *Journal of Applied Ecology* 42: 208–217.

Paria, K., S.M. Mandal, and S.K. Chakroborty. 2017. Simultaneous removal of Cd(II) and Pb (II) using a fungal isolate, Aspergillus penicillioides (F12) from Subarnarekha Estuary. *International Journal of Environmental Research* 12 (1): 77–86.

Patra, M.K., S.K. Acharjee and S.K. Chakraborty 2004. Economic productivity of bheri fisheries in relation to some management factors in North-East Sundarbans , India. *Journal of the Inland Fisheries Society of India* 36 (1): 23–28.

Patra, M.K., S.K. Acharjee, and S.K. Chakraborty. 2005. Conservation categories of siluroid fishes in North-East Sundarbans, India. *Biodiversity and Conservation* 14: 1863–1876.

Peduzzi, P., and B. Luel. 2008. Viruses, bacteria and suspended particlesin a backwater and main channel site of the Danube (Austria). *Aquatic Sciences* 70: 4429–4438.

Pejler, B. 1957. Taxonomical and ecological studies on planktonic Rotatoria from northern Swedish Lapland. K. svenska Vetensk Akad Handl., Ser. 4, bd 6 no 68 pp.

———. 1977. On the global distribution of family Brachionidae (Rotatoria). *Archiv fur Hydrobiologie* 53 (Suppl): 255–306.

Pennak, R.W. 1978. *Fresh water invertebrates of the United States*, 1–803. New York: Wiley.

Perrings, C., and M. Gadgil. 2003. Conserving biodiversity: reconciling local and global public benefits. In *Providing global public goods: Managing globalization*, ed. I. Kaul, P. Conceicao, K. le Goulven, and R.L. Mendoza, 532–555. Oxford: Oxford University Press.

Perrings, C., S. Baumgartner, W.A. Brock, K. Chopra, M. Conte, C. Costello, A. Duraiappah, A.P. Kinzig, U. Pascul, S. Polsky, J. Tschirhrt, and Xeppdes. 2009. The economics of biodiversity and ecosystem services. In *Biodiversity, ecosystem functioning, and human wellbeing: An ecological and economic perspective*, ed. S. Neem, D. Bunker, Hector, M. Loreau, and C. Perrings, 230–247. Oxford: Oxford University Press.

Perrings, C., S. Naeem, S. Farshid, et al. 2011. Ecosystem services, targets and indicator for the conservation and sustainable use of biodiversity. *Frontiers in Ecology and the Environment* 9 (9): 512–520.

Petchey, O.L. 2004. On the statistical significance of functional diversity. *Functional Ecology* 18: 297–303.

Petchey, O.L., and K.J. Gaston. 2002a. Extinction and the loss of functional diversity. *Proceedings of the Royal Society of London B* 269: 1721–1727.

———. 2002b. Functional diversity (fd), species richness, and community composition. *Ecology Letters* 5: 402–411.

———. 2006. Functional diversity: Back to basics and looking forward. *Ecology Letters* 9: 741–758.

Petchy, O.L., A. Hector, and K.J. Gaston. 2004. How do different measures of functional diversity perform ? *Ecology* 85: 847–857.

Philips, R.C. 1960. Observations on the ecology and distribution of Florida seagrasses. *Florida State Board of Conservation, Marine Laboratory* 2: 1–72.

Poinar, H.N., M. Hofreiter, G.S. Spaulding, P.S. Martin, A.B. Stankiewicz, H. Bland, R.P. Evershed, G. Possnert, and S. Paabo. 1998. Molecular coproscopy: Dung and diet of the extinct ground sloth, *Nothrotheriops shastensis*. *Science* 281: 402–406.

Pollock, M.M., R.J. Naiman, and T.A. Hanley. 1998. Plant species richness in riparian wetlands: A test of biodiversity theory. *Ecology* 79: 94–105.

Pourriot, R. 1965. Recherches sur I'ecologie des Rotiferes. *Vie et Milieu* 21 (Suppl): 1–224.

Power, M.E. 1990. Effects of fish in river food webs. *Science* 250: 811–814.

Power, M.E., W. Matthews, and A. Stewart. 1985. Grazing minnows, piscivorous bass, and streams algae: Dynamics of a strong interaction. *Ecology* 66: 1448–1456.

Pradhan, P., and S.K. Chakraborty. 2006. Diversity of zooplanktonic rotifers of river Shilabati, West Midnapore District, West Bengal, India. *Aquaculture* 7 (1): 99–117.

———. 2008. Ecological study of rotifera and its application for biomonitoring freshwater riverine environment. *Zoological Research in Human Welfare* Paper-31: 289–306.

Pradhan, P., S.S. Mishra, R. Majumder, and S.K. Chakraborty. 2003. Environmental monitoring with special emphasis on bio-monitoring – a prerequisite for sustainable environmental management: A case study in Darkeswar river of South West Bengal, India. In *Environment pollution and management*, ed. A. Kumar, C. Bhora, and L.K. Sing, 87–103. New Delhi: Ashish Publishing Corporation.

Pradhan, P., S.S. Mishra, S.K. Chakraborty, and R.K. Bhakat. 2005. Diversity of freshwater macrophytic vegetation of six rivers of South West Bengal, India. *Tropical Ecology* 46 (2): 193–202.

Pradhan, P., S. Giri, and S.K. Chakraborty. 2006. Ecological gradients determining the density and diversity of rotifera in a fresh water river system of South West Bengal, India. *Journal of Aquatic Biology* 21 (1): 19–28.

———. 2008. Zooplanktonic rotifers in river Kansai, West Bengal, India. *Journal of Indian Fisheries Society of India* 39 (2): 43–47.

Pringle, C.M., M.C. Freeman, and B.J. Freeman. 2000. Regional effects of hydrological alterations on riverine macrobiota in the New World: Tropical-temperate comparisons. *Biocontrol Science* 50: 807–823.

Raffaelli, D. 2004. How extinction patterns affect ecosystems. *Science* 306: 1141–1142.

Raaffaelli, D.G., Emmerson , M., Solan , M., Biles , C.L., & Paterson , D.M. 2002. Biodiversity and ecosystem functioning in shallow coastal waters: an experimental approach. *Journal of Sea Research* 316: 1–9.

Raghunathan, M.B. 1990a. Seasonal studies of fresh water cladocera of Chinglepet tank, Tamil Nadu. *Records of Zoological Survey of India* 86 (2): 253–259.

———. 1990b. Seasonal studies of fresh water cladocera of Chinglepet tank, Tamil Nadu. *Records of Zoological Survey of India* 86 (2): 253–259.

Raghunathan, M.B., and R. Suresh Kumar. 2006. Diversity of rotifers of Tamil Nadu. *Records of Zoological Survey of India* 106 (part -2): 67-28.

Rahbek, C. 1995. The elevational gradient of species richness: A uniform pattern? *Ecography* 18: 200–205.

Rainboth, W.J. 1996. *Fishes of the Cambodian Mekong*. Rome: Food and Agriculture Organization U. N, 265 pp.

Reddy, Y.R. 1994. *Copepoda: Calanoida: Diaptomidae: Guide to the identification of the microinvertebrates of the continental waters of the world*. Coordinating Ed., H.J.F. Dumont. SPB Academic Pubishing bv. pp. 1–221

Reddy, Y. R. 2001. Zooplankton diversity: Fresh water planktonic copepoda with key to common calanoid and cyclopoid genera in India. In *Water quality assessment, biomonitoring and zooplankton diversity*, ed. B.K. Sharma, 174–189.

Reinhard, E.G. 1931. The plankton ecology of the upper Mississippi Mininneapolis to Winona. *Ecol. Monogr.* 1 (7): 139–148.

Rhoads, D.C., and L.F. Boyer. 1982. The effects of marine benthos on physical properties of sediments: A successional perspective. In *Animal-sediment relations*, ed. P.L. McCall and M.J.S. Tevesz, 3–52. New York: Plenum/Springer.

Rice, Stephen P., R.L. Ferguson, and T.B. Hoey. 2006. Tributary control of physical heterogeneity and biological diversity at river confluences. *Canadian Journal of Fisheries and Aquatic Sciences* 63 (11): 2553–2566.

Rice, S.P., P. Kiffney, C. Greene, and G.R. Pess. 2008. The ecological importance of tributaries and confluences. In *River confluences , tributaries and the fluvial network*, ed. S.P. Rice, A.G. Roy, and B.L. Rhoads, 2–242. Wiley.

Richardson, S.J., M.C. Press, A.N. Parsons, and S.E. Hartley. 2002a. How do nutrients and warming impact on plant communities and their insect herbivores? A 9-year study from a sub-Arctic heath. *Journal of Ecology* 90: 544–556.

———. 2002b. How do nutrients and warming impact on plant communities and their insect herbivores? A 9-year study from a sub-Arctic heath. *Journal of Ecology* 90: 544–556.

Richardson, S.J., D.A. Peltzer, R.B. Allen, M.S. McGlone, and R.L. Parfitt. 2004a. Rapid development of phosphorus limitation in temperate rainforest along the Franz Josef soil chronosequence. *Oecologia* 139: 267–276.

———. 2004b. Rapid development of phosphorus limitation in temperate rainforest along the Franz Josef soil chronosequence. *Oecologia* 139: 267–276.

Riemann, B., and M. Søndergaard. 1986a. *Carbon dynamics of eutrophic temperate lakes*. Amsterdam: Elsevier.

———. 1986b. *Carbon dynamics of eutrophic temperate lakes*. Amsterdam: Elsevier.

Ritz, D.A., and G.W. Hosie. 1982a. Production of the euphausiid Nyctiphanes australis in Storm Bay, south-eastern Tasmania. *Marine Biology* 68: 103–108.

———. 1982b. Production of the euphausiid Nyctiphanes australis in Storm Bay, south-eastern Tasmania. *Marine Biology* 68: 103–108.

Robinson, C.T., and M.O. Gessner. 2000. Nutrient addition accelerates leaf breakdown in analpine spring brook. *Oecologia (Berlin)* 122: 258–263.

Rocha, O., T. Matsumura-Tundisi, E.L.G. Espindola, K.F. Roche, and A.C. Rietzler. 1999a. Ecological theory applied to reservoir zooplankton. In *Theoretical reservoir ecology and its applications*, ed. J.G. Tundisi and M. Straskraba, 457–476. Sao Carlos: International Ecology Institute/Backhuys Publishers.

———. 1999b. *Ecological theory applied to reservoir zooplankton*, 457–476. J.G. Tundisi and M. Straskraba.

Rohde, K. 1992. Latitudinal gradients in species diversity: The search for the primary cause. *Oikos* 65: 514–527.

Root, R.B. 1967. *The niche exploitation patterns of the blue-grey gnatcatcher*, Ecological monographs. Vol. 37, 317–350. Rotjan and Idjadi, 2013.

Rosenberg, M.J., D.C. Adams, and J. Gurevitch. 2000. *Metawin 2.0 user's manual: Statistical software for meta-analysis*. Sunderland: Sinauer Associates.

Rosenberger, R.S., and J.B. Loomis. 2000. Using metaanalysis for benefit transfer: in-sample convergent validity tests of an outdoor recreation database. *Water Resources Research* 36: 1097–1107.

Ruppert, E.E. and Barnes, R.D. 1995. Sponges and placozoans. In Invertebrate Zoology: 6th Edtn. Saunders College Publishing. New York: 73–94.

Ryszkowski, L., and Bartoszewicz. 1989. Impact of agricultural landscape structure on cycling of inorganic nutrients. In *Ecology of arable land*, ed. M. Clarholm and L. Bergstrom, 241–246. Dordrecht: Kluwer Academic Publishers.

Sabo, J.L., R. Sponseller, M. Dixon, K. Gade, T. Harms, J. Heffernan, A. Jani, G. Katz, C. Soykan, J. Watts, and J. Welter. 2005. Riparian zones increase regional species richness by harboring different, not more, species. *Ecology* 86: 56–62.

Sacotte, S., and P. Magnan. 2006. Inherited differences in foraging behaviour in offspring of two forms of lacustrine brook charr. *Evolutionary Ecology Research* 8 (5).

Sala, O.E., F.S. Chapin, J.J. Armesto, E. Berlow, J. Bloomfield, R. Dirzo, E. Huber-Sanwald, L.F. Huenneke, R.B. Jackson, A. Kinzig, R. Leemans, D.M. Lodge, H.A. Mooney, M. Oesterheld, N.L. Poff, M.T. Sykes, B.H. Walker, M. Walker, and D.H. Wall. 2000. Global biodiversity scenarios for the year 2100. *Science* 287: 1770–1774.

Schindler, D.W., P.J. Curtis, S.E. Bayley, B.R. Parker, K.G. Beaty, and M.P. Stainton. 1997. Climate-induced changes in the dissolved organic carbon budgets of boreal lakes. *Biogeochemistry* 36: 9–28.

Schlapfer, F., and B. Schmid. 1999. Ecosystem effects of biodiversity: A classification of hypotheses and cross-system exploration of empirical results. *Ecological Application* 9: 893–912.

Schmid, B., A. Hector, M. Huston, P. Inchausti, I. Nijs, P. Leadley, and D. Tilman. 2002a. The design and analysis of biodiversity experiments. In *Biodiversity and ecosystem functioning: Synthesis and perspectives*, ed. M. Loreau, S. Naeem, and P. Inchausti, 61–75. New York: Oxford University Press.

Schmid, B. 2002b. The species richness–productivity controversy. *Trends in Ecology & Evolution* 17: 113–114.

Schneider, R.L., and R.R. Sharitz. 1988. Hydrochory and regeneration in a bald cypress-water tupelo swamp forest. *Ecology* 69: 1055–1063.

Schoener, T. 1991. Extinction and the nature of the metapopulation. *Acta Oecologia* 12: 53–75.

Scholten, M., A. Anlauf, B. Büchele, P. Faulhaber, K. Henle, S. Kofalk, I. Leyer, J. Meyerhoff, J. Purps, G. Rast, and M. Scholz. 2005. The River Elbe in Germany—Present state, conflicting goals, and perspectives of rehabilitation. *Archiv für Hydrobiologie Supplement band* 155: 579–602.

Seehausen, O. 2006. Conservation: losing biodiversity by reverse speciation. *Current Biology* 16: R334–R337.

Seehausen, O., G. Takimoto, D. Roy, and J. Jokela. 2007. Speciation reversal and biodiversity dynamics with hybridization in changing environments. *Molecular Ecology (Blackwell Publishing Ltd.)*: 1–14.

Serafim, M., Jr., F.A. Lansac-Toha, J.C. Paggi, L.F.M. Velho, and B. Robertson. 2003. Cladocera fauna composition in a River-Lagoon system of the upper Parana river floodplain, with a new record for Brazil. *Brazilian Journal of Biology* 63 (2): 349–356.

Sharma, B.K. 1983. The Indian species of the genus, Brachionus (Eurotatoria: Monogonta: Brachionidae). *Hydrobiologia* 104: 31–39.

———. 1991. Rotifera. In *Animal resources of India – State of art*, 69–88. Z.S.I. publications.

———. 1992. Freshwater rotifers (Rotifera:Eurotatoria). In *Fauna of west Bengal, State fauna series, 3(13)*, 1–121. Calcutta: Zoological Survey of India.

———. 1993. Freshwater Rotifes (Rotifera: Eurotatoria). In *Fauna of West Bengal. State Fauna series, 3 (13)*, 1–121. Calcutta: Zoological Survey of India.

———. 1998. In *Faunal diversity of India*, ed. J.R.B. Alfred, A.K. Das, and A.K. Sanyal, 57–70. Zoological Survey of India, Environmental Centre.

———. 2001. Biomonitoring and role of Rotifera. In *Water quality assessment, biomonitoring and zooplankton diversity*, ed. B.K. Sharma, 83–95. Shillong: Department of Zoology, NEHU.

Sharma, B.K., and S. Sharma. 1990. On the taxonomic status of some cladoceran taxa (Crustacea: Cladocera) from Central, India. *Revue d'hydrobiologie Tropicale* 23 (2): 105–113.

Sharma, A., et al. 1999a. Studies on zooplankton community of the Tungabhadra river in Karnataka receiving domestic sewage from Harihar region. *Journal of Environment & Pollution* 6 (2&3): 161–166.

———. 1999b. Studies on zooplankton community of the Tungabhadra river in Karnataka receiving domestic sewage from Harihar region. *Journal of Environment & Pollution* 6 (2&3): 161–166.

Shigesada, N., and K. Kwasaki. 1997. *Biological invasions: Theory and practice*. Oxford: Oxford University Press.

Shurin, J.B., E.T. Borer, E.W. Seabloom, K. Anderson, C.A. Blanchette, B. Broitman, S.D. Cooper, and B.S. Halpern. 2002. A cross-ecosystem comparison of the strength of trophic cascades. *Ecology Letters* 5: 785–791.

Shurin, J.B., D.S. Gruner, and H. Hillebrand. 2006. All wet or dried up? Real differences between aquatic and terrestrial food webs. *Proceedings of the Royal Society B: Biological . Sciences* 273: 1–9.

Simonson, W.D., H.D. Allen, and D.A. Coomes. 2014. Overstorey and topographic effects on understories: Evidence for linkages from cork oak (*Quercus suber*) forests in southern Spain. *Forest Ecology and Management* 328: 35–44.

Sinha, R.K. 1992. Rotifer population of Ganga near Paba, Bihar (India), Proceedings of the National Academy of Sciences, India Section B. ll: 313–322.

Sinha, M. 2000. *Ecology and fisheries of Beels in West Bengal*. Bulletine No. 103, 1−53.

Siqueira, Tadeu, Luis Mauricio Bini, Sidinei Magela Thomaz, and Diego Fontaneto. 2015. Biodiversity analyses: are aquatic ecologists doing any better and differently than terrestrial ecologists? *Hydrobiologia* 750: 5–12.

Sladecek, V. 1983. Rotifers as bioindicators of water quality. *Hydrobiology* 100: 169–201.

———. 1995. Rotifers as test system for pollution monitoring. In *Pollution studies*, ed. B.C. Rana. Karad: Environmental Publications.

Snyder, W.E., and A.R. Ives. 2003. Interactions between specialist and generalist natural enemies: parasitoids, predators, and pea aphid biocontrol. *Ecology* 84: 91–107.

Slobodkin, L.B. 2003. *A citizen's guide to ecology*. New York: Oxford University Press.

Smith, T.B., and S. Skulason. 1996. Evolutionary significance of resource polymorphisms in fishes, amphibians and birds. *Annual Review of Ecology and Systematics* 27: 111–133.

Smith, P., and J. Smith. 1990. Floodplain vegetation. In *The Murray*, ed. N. Mackay and D. Eastburn, 215–228. Canberra: Murray-Darling Basin Commission.

Solan, Martin, Jasmin A. Godbold, Amy Symstad, F. Dan, B. Flynn, and N.D. Martinez. 1992. Constant connectance in community food webs. *American Naturalist* 139: 1208–18.330.

Solan, M., B.J. Cardinale, A.L. Downing, K.A.M. Engelhardt, J.L. Ruesink, and D.S. Srivastava. 2004. Extinction and ecosystem function in the marine benthos. *Science* 306: 1177–1180.

Soule, M.E. 1990. The onslaught of alien species and other challenges in the coming decades. *Conservation Biology* 4: 233–239.

Staniferth, R.J., and P.B. Cavers. 1976. An experimental study of water dispersal in Polygonium spp. *Canadian Journal of Botany* 54: 2587–2596.

Steiger, J., E. Tabacchi, S. Dufour, Corenblit, and J.L. Peiry. 2005. Hydromorphic processes affecting riparian habitat within alluvial channel – floodplain river systems: A review for the temperate zone. *River Research and Applications* 21: 719–737.

Steinman, A.D., K.E. Havens, N.G. Aumen, R.T. James, K.R. Jin, J.J. Zhang, and B. Rosen. 1999. Phophorus in Lake Okeechobee: sources, sinks and strategies. In *Phosphorus biogeochemistry of subtropical ecosystems: Florida as a case example*, ed. K.R. Reddy, G.A. O'Connor, and C. L. Schelske, 527–544. New York: CRC/Lewis.

Steinman, A., A.K. Havens, and L. Hornung. 2002. The managed recession at Lake Okeechobee, Florida: integrating science and natural resource management. *Conservation Ecology* 6 (2): 17.

Stevens, G.C. 1989. The latitudinal gradient in geographical range: How so many species coexist in the tropics. *The American Naturalist* 133 (2): 240–256.

Stevens, L.E., J.C. Schmidt, T.J. Ayers, and B.T. Brown. 1995. Flow regulation, geomorphology, and Colorado River marsh development in the Grand Canyon, Arizona. *Ecological Applications* 5: 1025–1039.

Stout, R.J. 1989. Effects of condensed tannins on leaf processing in mid-latitude and tropical streams: A theoretical approach. *Canadian Journal of Fisheries and Aquatic Sciences* 46: 1097–1106.

Strauss, E.A., and W.K. Dodds. 1997. Influence of protozoa and nutrient availability on nitrification rates in subsurface sediments. *Microbial Ecology* 34: 155–165.

Strauss, E.A., W.B. Richardson, J.C. Cavanaugh, L.A. Bartsch, R.M. Kreiling, and A.J. Standorf. 2006. Variability and regulation of denitrification in an Upper Mississippi River backwater. *Journal of the North American Benthological Society* 25: 596–606.

Strayer, D.L. 1999. Effects of alien species on fresh water mollusks in North America. *Journal of the North American Benthological Society* 18: 74–98.

Strayer, D.L., and S.E.G. Findlay. 2010. Ecology of freshwater shore zones. *Aquatic Sciences* 72: 127–163.

Strayer, D., and W.D. Hummon. 1991. Gastrotricha. In *Ecology and classificationof North American freshwater invertebrates*, ed. J.H. Throp and A.P. Covich, 177–189. Orlando: Academic.

Strayer, D.L., E. Stuart, G. Findlay, Daniel Miller, Heather M. Malcom, David T. Fischer, and Thomas Coote. 2012. Biodiversity in Hudson River shore zones: Influence of shoreline type and physical structure. *Aquatic Sciences* 74: 597–610. https://doi.org/10.1007/s00027-012-0252.

Suberkropp, K., and H.S. Weyers. 1996. Application of fungal and bacterial production methodologies to decomposing leaves in streams. *Applied and Environmental Microbiology* 62: 1910–1615.

Suttle, K.B., M. Power, J.M. Levine, and C. Mcneely. 2004. How fine sediment in riverbeds impairs growth and survival of juvenile salmonids. *Ecological Applications* 14 (4): 969–974.

Tabacchi, E., A.-M. Planty-Tabacchi, M.J. Salinas, and H. De'camps. 1996. Landscape structure and diversity in riparian plant communities: A longitudinal comparative study. *Regulated Rivers* 12: 367–390.

Talwar, P.K., and R.K. Kacker. 1984. Commercial Sea fishes of India. *Zoological Survey of India, Calcutta* 977.

Taylor, C.D. 1980. Methane cycling in aquatic environments. *Advances in Aquatic Microbiology* 2: 77–150.

Thirakhupt, K., and P.P. Van Dijk. 1994. Species diversity and conservation of turtles in westem Thailand. *Natural History Bulletin of the Siam Society* 42: 207–259. 84.

Tilman, D. 1982. *Resource Competition and Community Structure*. Princeton: Princeton University Press.

———. 1999. The ecological consequences of changes in biodiversity: The search for general principles. *Ecology* 80: 1455–1474.

Tilman, D., C.L. Lehman, and C.E. Bristow. 1998. Diversity-stability relationships: Statistical inevitability or ecological consequence? *American Naturalist* 151: 277–282.

Tilman, D., P.B. Reich, J. Knops, D. Wedin, T. Mielke, and C. Lehman. 2001. Diversity and productivity in a long-term grassland experiment. *Science* 294: 843–845.

Treplin, M., and M. Zimmer. 2012. Drowned or dry: A crosshabitat comparison of detrital breakdown processes. *Ecosystems* 15: 477–491.

Trivedy, R.K., and P.K. Goel. 1984. *Chemical and biological methods for water pollution studies*, 1–215. Karad: Environmental Publications, I–XXXII.

Turner, R.E., and N.N. Rabalais. 1994. Coastal eutrophication near the Mississippi river delta. *Nature* 368: 619–621.

Tockner, K., and J.A. Stanford. 2002. Riverine flood plains: Present state and future trends. *Environmental Conservation* 29: 308–330.

Underwood, A.J. 1994. On beyond BACI: Sampling designs that might reliably detect environmental disturbances. *Ecological Applications* 4: 3–15.

van Jaarsveld, A.S., R. Biggs, R.J. Scholes, E. Bohensky, B. Reyers, T. Lynam, C. Musvoto, and C. Fabricius. 2005. Measuring conditions and trends in ecosystem services at multiple scales: The Southern African Millennium Ecosystem Assessment experience. *Philosophical Transactions of Royal Society of London. B. Biological Sciences* 360 (1454): 425–441.

Vanni, M.J. 2002. Nutrient cycling by animals in freshwater ecosystems. *Annual Review of Ecology and Systematics* 33: 341–370.

Vanni, and C.D. Layne. 1997. Nutrient recycling and herbivory of mechanisms in the " top down " effects of fish on phytoplankton in lakes. *Ecology* 78: 21–41.

Vanni, M.J., C.D. Layne, and S.E. Amott. 1997. "Top down" trophic interactions inlakes: effects of fish on plankton and nutrient dynamics. *Ecology* 78: 1–20.

Vannote, R.L., and B.W. Sweeney. 1980. Geographic analysis of themal equilibria: a conceptual model for evaluating the effect of natural and modified thermal regimes on aquatic insect communities. *The American Naturalist* 115: 667–695.

Vannote, R.L., G.W. Minshall, K.W. Cummi, J. Sedell, and C.E. Cushing. 1980. The river continuum concept. *Canadian Journal of Fisheries and Aquatic Sciences* 37: 130–137.

Verschuere, L., G. Rombaut, P. Sorgeloos, and W. Verstraete. 2001. Probiotic bacteria as biological control agents in aquaculture. *Microbiology and Molecular Biology Reviews* 64 (4): 655–671.

Vitousek, P.M., H.A. Mooney, J. Lubchenco, and J.M. Melillo. 1997. Human domination of earth's ecosystems. *Science* 277: 494–499.

Vitousek, P.M., J.D. Aber, R.W. Howarth, G.E. Likens, P.A. Matson, D.W. Schindler, et al. 1997. Human alteration of the global nitrogen cycle: Sources and consequences. *Ecological Applications* 7: 737–750.

Vitousek, P.M., K. Cassman, C. Cleveland, et al. 2002. Towards an ecological understanding of biological nitrogen fixation. *Biogeochemistry* 57: 1–45.

Vörösmarty, C.J., P.B. McIntyre, M.O. Gessner, D. Dudgeon, A. Prusevich, P. Green, S. Glidden, S.E. Bunn, C.A. Sullivan, C.R. Liermann, and P.M. Davies. 2010. Global threats to human water security and river biodiversity. *Nature* 467: 555–561.

Wagner, C.M., and H.M. Austin. 1999. Correspondence between environmental gradients and summer littoral fish assemblages in low salinity reaches of the Chesapeake Bay, USA. *Marine Ecology Progress Series* 177: 197–212.

Walker, B.H. 1992. Biodiversity and ecological redundancy. *Conservation Biology* 6: 18–23.

Wallace, J.B., and J.R. Webster. 1996. The role of macroinvertebrates in stream ecosystem function. *Annual Review of Entomology* 41: 115–139.

Wallberg, P., P.R. Jonsson, and R. Johnstone. 1999. Abundance, biomass and growth rates of pelagic microorganisms in a tropical coastal ecosystem. *Aquatic Microbiology and Ecology* 18: 175–185.

Wallace, J.B., S.L. Eggert, J.L. Meyer, and J.R. Webster. 2007. Multiple trophic levels of a forest streams linked to terrestrial litter inputs. *Science* 277: 102–104.

Wallace, J.B., J.R. Webster, and T.F. Cuffney. 1982. Stream detritus dynamics: Regulation by invertebrate consumers. *Oecologia (Berlin)* 53: 197–200.

Wallace, J.B., J.W. Grubaugh, and M.R. Whiles. 1996. Biotic indices and stream ecosystem processes: Results from an experimental study. *Ecological Applications* 6: 140–151.

———. 2007. *Multiple trophic levels of a forest stream linked to terrestrial litter inputs*

Walsh, C.J., K.A. Waller, J. Gehling, and R. Mac Nally. 1998a. Riverine landscapes: biodiversity patterns, disturbance regimes and aquatic conservation. *Biological Conservation* 83: 267–278.

———. 1983b. Thermal responses in the evolutionary ecology of aquatic insects. *Annual Review of Entomology* 27: 97–118.

———. 1983c. The intermediate disturbance hypothesis: an explanation for biotic diversity patterns in lotic ecosystems. In *Dynamics of lotic ecosystems*, ed. T.D. Fontaine and S.M. Bartell. Ann Arbor: Ann Arbor Science Publishers.

———. 1995a. The serial discontinuity concept: Extending the model to floodplain rivers. *Regulated Rivers* 10: 159–168.

———. 1995b. Ecological connectivity in alluvial river ecosystems and its disruption by flow regulation. *Regulated Rivers: Research & Management* II: 105–119.

Walsh, C.J., K.A. Waller, J. Gehling, and R. Mac Nally. 2007. Riverine invertebrate assemblages are degraded more by catchment urbanization than by riparian deforestation. *Freshwater Biology* 52: 574–587.

Ward, J.V. 1989. The four-dimensional nature of lotic ecosystems. *Journal of the North American Benthological Society* 8: 2–8.

Ward, J.V. 1989. The four-dimensional nature of lotic ecosystems. *Journal of the North American Benthological Society* 8: 2–8; 37:130–137.

Ward, J.V., and J.A. Stanford. 1983. The serial discontinuity concept of lotic ecosystems. In *Dynamics of lotic ecosystems*, ed. T.D. Fontaine III and S.M. Bartell. Ann Arbor: Ann Arbor Science.

Ward, J.V., K. Tockner, and F. Schiemer. 1999. Biodiversity of floodplain river ecosystems: Ecotones and connectivity. *Regulated Rivers: Research and Management* 15: 125–139.

Ward, J.V., K. Tockner, D.B. Arscott, and C. Claret. 2002. Riverine landscape diversity. *Freshwater Biology* 47: 57–539.

Waters, T.F. 1995. *Sediment in streams: sources, biological effects and control*, American Fisheries Society Monograph 7. Bethesda: American Fisheries Society. 251pp.

Waters, T.F., M.T. Doherty, and C.C. Krueger. 1990. *Annual production and production: biomass ratios for three species of stream*

Webb, J.A., and E.L. King. 2009. A Bayesian hierarchical trend analysis finds strong evidence for largescale temporal declines in stream ecological condition around Melbourne, Australia. *Ecography* 32: 215–225.

Webb, R.H., J.C. Schmidt, and M. Collier. 1996. *Dams and rivers: A primer on the downstream effects of dams*, Geological Survey circular No. 1126. Denver: U.S. Geological Survey.

Webster, J.R., and J.L. Meyer. 1997. Stream organic matter budgets. *Journal of the North American Benthological Society* 16: 3–161.

Webster, J.R., and B.C. Patten. 1979. Effects of watershed perturbation on stream potassium and calcium dynamics. *Ecological Monographs* 19: 51–72.

Webster, J.R., J.B. Wallac, and E.F. Benfield. 1995. Organic processes in streams of the eastern United States. In *River and stream ecosystems*, ed. C.E. Cushing, K.W. Cummins, and G.W. Minshall, 117–187. Amsterdam: Elsevier Science.

Webster, J.R., E.F. Benfield, T.P. Ehrman, M.A. Schaefer, J.L. Tank, J.J. Hutchens, and D.J. D'Angelo. 1999. What happens to allochthonous material that falls into streams ? A synthesis of new and published information from Coweeta. *Freshwater Biology* 41: 687–705.

Wetmore, S.H., R.J. Mackay, and R.W. Newbury. 1990. Characterization of the hydraulic habitat of *Brachycentrus occidentalis*, a filter feeding caddisfly. *Journal of the North American Benthological Society* 9 (2).

Wetzel, R.G. 2001. *Limnology: Lake and river ecosystems*. 3rd ed. San Diego: Elsevier, 1006 pp.

Whitman, W.B., D.C. Coleman, and W.J. Wiebe. 1998. Prokaryotes: The unseen majority. *Proceedings of the National Academy of Science, U.S.A* 95: 6578–6583.

Whittaker, R.H. 1975. *Communities and ecosystems*. 2nd ed. New York: The Macmillan and Co.

Wiens, J.A. 2002. Riverine landscapes: taking landscape ecology into the water. *Freshwater Biology* 47: 501–515.

Williams, R.J., and N.D. Martinez. 2000. Simple rules yield complex food webs. *Nature* 404: 180–183.

Williamson, M.H. 1996. *Biological invasions*. London: Chapman and Hall.

Wilson, E.O. 1986. *Biophilia*. Cambridge, MA: Harvard University Press.

Winner, J.M. 1975. Zooplankton. In *Studies in ecology, Vol. 2*, River ecology, ed. B.A. Whitton, 155–169. Oxford/London/Edinburgh/ Melbourne: Blackwell Scientific Publication.

Woodin, S.A. 1999. Shallow water benthic ecology: A north American perspective of sedimentary habitats. *Australian Journal of Ecology* 24: 291–301.

Wootton, J.T., M. Parker, and M. Power. 1996. Effects of disturbance on river food webs. *Science* 273 (5281): 1558–1561.

———. 1992. *The diversity of life*. Princeton: Princeton University Press.

Wootton, J.T. 1998. Effects of disturbance on species diversity: A multitrophic perspective. *American Naturalist* 152: 803–825.

Wright, J.P., S. Naeem, A. Hector, C. Lehman, P.B. Reich, B. Schmid, and D. Tilman. 2006. Conventional functional classification schemes underestimate the relationship with ecosystem functioning. *Ecology Letters* 9: 11–120.

Wu, J., and O.L. Loucks. 1995. From balance of nature to hierarchical patch dynamics: A paradigm shift in ecology. *Quarterly Review of Biology* 70: 439–466.

Wu, J. 1999. Hierarchy and scaling: extrapolating information along a scaling ladder. *Canadian Journal of Remote Sensing* 25: 367–380.

Wu, J., and O.L. Loucks. 1995. From balance of nature to hierarchical patch dynamics: a paradigm shift in ecology. *Quarterly Review of Biology* 70: 439–466.

Yule, C.M. 1996. Trophic relationships and food webs of the benthic invertebrate fauna of two aseasonal tropical steams on Bougainville Island, Papua New Guinea. *Journal of Tropical Ecology* 12: 517–534.

Yule, C.M., and R.G. Pearson. 1996. Seasonality of benthic invertebrates in a tropical stream on Bougainville Island, Papua New Guinea. *Archiv für Hydrobiologie* 137: 95–117.

Yvon-Durocher, G., J. Reiss, J. Blanchard, B. Ebenman, D.M. Perkins, D.C. Reuman, A. Thierry, G. Woodward, and O.L. Petchey. 2011. Across ecosystem comparisons of size structure: Methods, approaches and prospects. *Oikos* 120: 550–563.

Zakaria-Ismail, M. 1994. Zoogeography and biodiversity of the freshwater fishes of Southeast Asia. *Hydrobiologia* 285: 41–48.

Zalewski, M., M. Lapinska, and I. Wagner. River ecosystems. Fresh Surface Water (Vol-II) River Ecosystems, pp. 1–14

Chapter 3
Ecology of Fishes of Rivers: Functional Roles

Abstract Fish and other fishery resources are representing most important faunal components in the riverine ecosystem by virtue of their vivid presence and functional roles towards stability of the lotic ecosystem. They are in utmost need of protection and conservation for themselves and their habitats because of the dependence of human beings on this gift of the nature as important sources of food (chief sources of proteins), from aquatic ecosystems.

Functional diversification of fishes, play important ecological roles acting as a major driver for altering the river biotic community as keystone predators by way of accelerating top-down trophic cascading effects which are revealed by the changes of species composition, size structure, and trophic relationships. Such predator-induced ecological changes in turn, facilitate to result evolutionary changes in the adaptive traits of different constituent species of the biotic communities. The term "**eco-evolutionary feedback**" refers to the process, involving the reciprocal interplay of ecology and evolution over contemporary timescales. The cumulative effect of all these biological entities in conjunction with different geo–hydro-ecological processes leads to impose considerable impact on ecosystem functioning such as energy flows and nutrient cycling.

The present chapter of this book has attempted to highlight the diversity, distribution, and ecological adaptabilities of fishes in the tropical riverine system citing case studies from the tropical riverine networks of the state of West Bengal, located in the eastern region of India, highlighting ecological threats on the fishes. Besides several biotic and habitat indices which have been devised in order to understand the pattern of distribution of fish in the river continuum system experiencing different ecological guilds are also included. In addition ,impact of ongoing environmental perturbation, especially in view of global climate changes on the eco-physiology of fishes and on the fishery-aquaculture sectors have been highlighted citing experimental studies mainly on the effects of temperature stresses on the morphoanatomy, physiology and biochemical parameters of culturable fishes, Indian Major Carps (I.M.C.).

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Keywords Diversity and classificatory scheme of riverine fishes · Morpho-anatomical excellence of fishes · Phenotypic plasticity · Eco-evolutionary feedback · Behavioral manifestation of fish · Migration in fish · River Continuum Concept vs ecological guilds of fish · Trophic polymorphism · Fish-based biotic integrity index (F-IBI) · Indian Major Carps · Temperature induced physiological stresses · Heat Shock Proteins (HSPs) · Biochemical constituents · Impact of global warming on fisheries · Conservation strategies

3.1 Intersections Among Ichthyology, Fishery Science, and Ecology

Fisheries or fish ecology is becoming a new discipline forged out of the intersection of three relatively distinct sciences: ichthyology, fisheries science, and ecology (Fig. 9.1). Ecology of relevance to fish and fisheries includes not only marine and freshwater ecology but also several ecotones such as river basins, floodplains, riparian forests etc. Its history is documented by Egerton (1983, 1985) and McIntosh (1985).

The early history of limnology can be found in Frey (1963) for North America and in Egerton (1983) in general, and of oceanography in Schlee (1973) or marine ecology in Egerton (1983). Fish were the common commodities of early expeditions around the globe. The history of fish ecology and fisheries science has been highlighted in the papers of McHugh (1970) and Egerton (2015). Some very basic ideas in ecology crystalized out of aquatic ecology, such as the trophic dynamic concept (Lindeman 1942; Cook 1977), the role of size-selective predation in structuring the size and species composition of communities (Hrbacek 1958; Hrbacek et al. 1961; Brooks and Dodson 1965), and the niche as an N-dimensional hypervolume (Hutchinson 1957). These ideas have been applied in fisheries and water quality management (Fig. 3.1). So many sister disciplines under the main discipline of ecology and fish and fisheries have emerged which are mentioned below.

3.1.1 Morpho-Anatomical Excellence with Evolutionary Past of Fish: Brief Classificatory Scheme

Fish were the first backboned animals to appear on earth, and they form by the largest group of vertebrates. Fish being cold blooded (ectothermic) vertebrates with streamlined body, mostly respire by gills with the exception in the order Dipnoi (lungs fishes). They are also characterized by comparative small sizes, but possessing light but strong internal skeleton, made up wholly or partly with bones, flexible paired, and unpaired fins, gas-filled swim bladder, different forms of scales

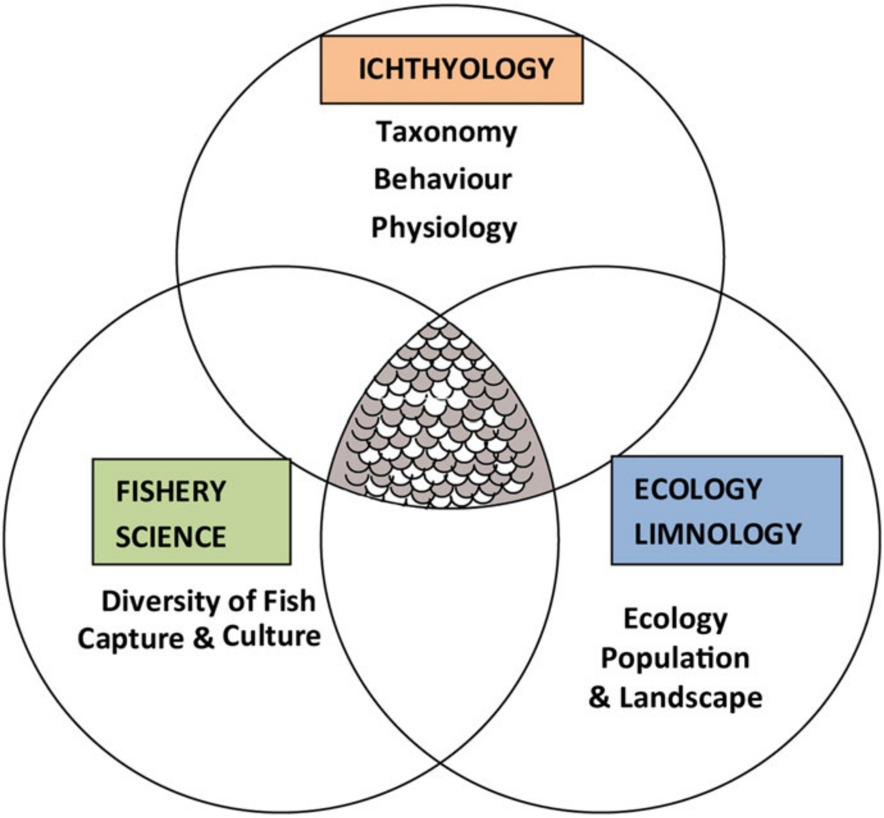

Fig. 3.1 Relationship among different aspects of study of fish – its biology, behavior, and ecology

(ctenoid, cycloid, etc.) of dermal origin. They are found to inhabit in all most all aquatic habitats including lakes, rivers, marshes, estuaries, and also in ocean.

As one of the primitive groups of vertebrates, fish might have been evolved from the protochordates around **500** million of years back. Out of the existing fishes of the world (The numbers of living fishes of the world are supposed to remain in between **25,000** and **30,000** species, while many others have become extinct during the course of evolution.

In the aquatic systems of the Indian subcontinent, around **2500** species of fishes are believed to exist, which exceeds far beyond the combined numbers of all other vertebrates species belonging to the classes of Mammalia, Aves, Reptilia, and Amphibia. The existing fishes, belonging to the class Pisces, are divided into three main groups: (**1**) Elasmobranchii, which includes cartilaginous fishes like sharks, skates, and rays; (**2**) Holocephali or Chimaerae, also cartilaginous but with single pointed, rat-like tail, and (**3**) Teleostomi, the bony fishes .which are further divided into (**a**) Dipnoi (lungfishes), the air breathing forms; (**b**) Coelacanths (lobe-finned fishes); and (**c**) Teleosts (the true bony fishes) which includes all the existing modern fishes such the carps, catfishes, ells, etc. from the fresh water habitats and mackerel, tuna, sardines from the saline water habitats.

Cartilaginous fish belonging to the class Chondrichthyes, subclass Elasmobranchii, **8** orders, **31** families and about **500** species. These primitive cartilaginous fish include some of the largest and successful predators in the marine-oceanic environment and includes **3** major groups: sharks, skates, and rays and a group of deep sea fish, called chimaeras. All possess a skeleton made up of cartilages, specialized sharp and replaceable teeth, and skin covered with small, dense, transparent scales. Although most of the cartilaginous fish are manie, but some sharks and rays enter freshwater and some tropical species live exclusively in freshwater. Bony fish belonging to the class Osteichthyes, includes **48** orders, **482** families, and more than **25,000** species.

The shapes of the body of most of the fishes are torpedo-like streamlined, tapering at both ends in order to experience least resistance while moving in the water. The body of fishes, divisible mostly into head, trunk, and tail are covered with different forms scales, excepting catfishes which are characterized in having long cat-like whiskers. The bony fishes have a common gill opening for all the gills, enclosed by an operculum while the cartilaginous possess separate gill slits for each gill. The absence of external ears is compensated by the development of internal ears which serves to maintain balance at the time of movement through water on receiving sound waves conducted through water. The unique body architectural plans have enabled the fish by adopting adaptations not only to withstand but overcome the ecological odds in respect of hydrostatic pressures, water temperature, density, and salinity of water, chasing for the preys, avoiding the attacks from the predators, etc.

3.1.2 Physiological Ecology and Fish

Fishes are heterothermic ectotherms that live in habitats that are thermally heterogeneous in time and space. Global climate warming resulting from increases of greenhouse gases in the atmosphere can be expected to alter significantly the temperatures and thermal structure of lakes, rivers, streams, and oceans and thereby determine the distribution, populations, and assemblages of fishes. Several water quality parameters such as temperature, salinity, and dissolved oxygen have been found to act as lethal, controlling, limiting, directive, and masking factors.

Knowledge of temperature as a directive factor, determined from laboratory experiments, could be used to predict the thermal habitat in which a fish chooses to live in nature through specific annual patterns of temperature change in terms of metabolism and growth. The metabolic consequences of ingestion, respiration, and excretion on growth are rather well-known for a number of fishes and can be modeled as a function of temperature (Kitchell et al. 1979; Hewett and Johnson 1987; Kitchell 1990; Wootton 1990).

3.1.3 *Relevance of Behavioral Ecology on Fish*

Synchronizing with the changing climatic factors, fishes tend to display different behavioral manifestations in the form of both vertical and horizontal migrations, different forms of parental care, selection of ecological guilds mostly by olfactory imprinting sense organs.

3.1.3.1 Phenotypic Plasticity: An Unique Adaptive Acquisition in Fish

Proximate causes are the mechanisms underlying behavior. Mechanisms tell us how behavior occurs. In terms of mechanisms, it is useful to think of an isosceles triangle (Fig 3.1) with the points labeled as nervous system, endocrine system, and immune system; all of the physiological processes that are basis of behavior. Outside the circle are myriad ecological and life history traits of the animals, bridging no functional and evolutionary aspects of behavior.

There has been a long-standing discussion concerning whether behavior is determined by genes or environmental factors. It is now accepted that environmental factors tend to regulate all kind of animal behaviors. It has been observed that epigenetic mechanisms of behavior as well as environmental variation that induces flexibility of individuals when they are confronted with different environmental or social circumstances.

3.1.3.2 Foraging Behavior

Collectively, animals consume a huge diversity of different food materials composing of several derivatives from animals and plants, for which several foraging strategies and approaches have been adopted by respective animal species in order to capture and process these foods. Furthermore different animal species utilize different diets in different stages of their life cycle and different individuals of the same age have different foraging adaptations and diets, called resource polymorphisms which support the proposition of an increased number of foraging strategies exceeding the number of total species.

Foraging involves an interrelated set of components which can usefully be categorized into a series of roughly sequential steps, at the extreme of which is represented by the choice of the general category of consumed foods along with the foraging habitats. Within the chosen habitat, the animal needs to locate, capture, and ingest the food items, while avoiding hazards such as predators, physical defenses, and toxins. The swallowed foods are then further processed in the digestive tract to separate absorbable components from wastes. Attempts have been made to categorize different groups of animals based on their existing foraging behaviors giving emphasis to different ecological and ethological attributes such as habitat selection, food choice, the pattern of foraging, food detection, food capture, and post-ingestive processing.

In aquatic habitats, some animals feed on the bottom (benthic), while others feed in the open water [pelagic in case of large lotic ecosystems (marine, rivers) or limnetic in the lentic ecosystem (lakes, ponds). Within each of these habitats, foraging might take place during the day (diurnal), at night (nocturnal), at dawn (matinal), or dusk (vespertine). Many animals forage in more than one habitat types such as amphibians and crocodiles forage on land and in water, while crepuscular animals are active both at dawn and dusk.

3.1.3.3 Breeding Behavior

Fishes inhabiting in freshwaters face constrains in finding out breeding sites as ecological conditions of the fish habitats are disturbed with over accumulation of silts and clays of the sediments, fungi, bacteria, and in many occasions with low oxygen levels which altogether pose great threats to their eggs in contrast to the relatively clear and clean waters of the sea. However, the fishes are able to solve the problems by displaying behavioral flexibility in respect of breeding adaptations in several ways. Most of the fishes inhabiting in the marine ecosystem breed frequently over their life span and produce large numbers of tiny eggs which after hatching form small, feebly drifting or sometimes free-swimming fry. This breeding practice is also followed by some larger inland species, the breeding of which are triggered by the current of water during floods, and the released eggs get maturity receiving the stimulus of flood. Such seasonal flooding with the higher volume and current of water loaded with allochthonous supply of food materials also stimulate the fishes to develop an urge to move upstream to far as possible before spawning, so that their buoyant, fast-developing eggs do not get swept out to the extreme downstream even to zone of estuarine influence. This kind of adaptive strategy enables the fishes to provide their fry not only suitable habitat space with least occurrences of predators but the availability of an abundant supply of suitable food such as planktons.

3.1.3.4 Migration of Fish: A Biomechanism for the Survival of Fish

The term migration is very intimately associated with fishes, and this phenomenon guides the classification of fishes too as short and long duration migration. The migration is defined as an adaptive response to spatial changes in the availability of resources and/or mortality risk. This definition applies to desperate taxa and yet recognizes migration as a singular phenomenon different from other types of movement. At the individual level, a hallmark of adaptive migration is represented as an uninterrupted movement in which reactions to stimuli as represented by the suitable habitats or temporary suppressions of foraging. At the level of the population, migration is a hypothesis to explain seasonal or other cyclical changes in the distribution of individuals. Thus migration being the central along the continuum of movements represented by foraging and commuting activities (vertical migration for an example) at one end and ranging or natal dispersal, i.e., metapopulation dynamics at the other.

Some migratory fish species travel long distances even swimming against currents displaying great strength and endurance to reach to the preferred habitats for the purpose of spawning. Besides migration of fishes from the seawater to freshwater, and vice versa require their efficient osmoregulatory abilities (McKeown 1984). According to their temperature requirements, species may also generally be referred to as cold water or warm water and gradations between. Many species of fish populations are very sensitive to change or deterioration of their habitat, including alteration of flows, temperature, and substrate quality. They tolerate only very small fluctuations in temperature and only reproduce under certain conditions. Many fish populations, therefore, are highly susceptible to many forms of habitat degradation, including alteration of flows, temperature, and substrate quality.

3.1.3.4.1 Adaptive Functions of Migration in Fish

The evolution of migratory behavior requires interaction between multitude of genetic determinants and environmental factors. The resulting suit of complex physiological and behavioral characters associated with migration has is often designated as migratory syndrome. One prominent example is the preemptive changes in morphology, coloration, osmoregulation, growth rate, and rheotaxis that accompany smoltification (metamorphosis from a stream dwelling to marine form) which enable a juvenile euryhaline fish species to leave natal streams to enter into the sea after achieving adaptabilities for surviving in the new ecological niches. To be adaptive, such changes must provide distinct advantages in terms of reproductive opportunities, energetics, and other prerequisites for survivability of the individual that outweighs the costs of movement and risks of starvation, predation, and reproductive failure as well as the costs and risks of not migrating. Further, the adaptive advantage of migration may be condition-dependent such that an individual may have higher fitness by becoming a non-migratory resident (partial migration).

The bio-ecological factors determining the motivations and movements of fish within a river ecosystem vary, and movement of adult fish may take place in the following manners:

1. Migrations in search for spawning grounds to undertake mating and laying fertilized eggs
2. Migrations in search for feeding zones within the riverine ecosystem for harvesting food resources
3. Seasonal or diurnal migrations in search for new habitats (to find out new habitats during summer, undertake overwintering migration and return to the previous

habitats at onset of favorable seasons; similarly movements to different habitats during night and day)

4. Movements to the different vertical strata of the water column in search of conducive thermal regimes

The hydraulic navigation strategies used by different stages in the life history of a migrating fish for identifying and selecting a path through a complex hydraulic field are generally unknown, unlike place-based habitat selection strategies used by resident fishes (Goodwin et al. 2006).

During their emigration phase, juvenile fishes undertake migration from small natal streams to become adult in the marine habitat after passing and overcoming the complex progression of flow fields of a small stream sizes to largest aquatic system. In order to have an insight of the mode of responses of fish to changing, and also to explain an integration of the life history of fish with biogeochemical cycles and fluvial geomorphology can help interpretation because fluid dynamics have had a role to interced both of these processes. A river without flow resistance does not face any force to distort the movement of an unit volume of water with an uniform motion initiated by the force of gravity (Leopold et al. 1964; Ojha and Singh 2002).

3.1.3.4.2 Ontogenic Shift Theory (O.N.S.): Adaptive Function of Migration at Population Level

Ontogenic shift theory (ONS) theory having an in-depth insight on the adaptive function of migration, predicts the body size depicting at which a change in niche (habitat, diet, and behavior) would provide an adaptive advantage by minimizing the ratio of mortality to growth. Interestingly, movement to a niche with higher mortality may be favored if there are sufficiently high opportunities for resource acquisition. More importantly, the **ONS** concept can be extended to reproductive stages as much as individual growth and cohort biomass are related to fecundity and fertility. For the vast majority of egg-laying fishes, fecundity increases approximately as a cube function of length; therefore, at least in females, strong selection for minimizing the mortality to growth ratio should be expected. Recognizing that a migration involves numerous character states and evolves in response to a suite of factors, it is clear that the ultimate cause for migration can vary simultaneously across species.

In accordance with types of migratory guilds, fish species are classified as diadromous (residing both saline water and freshwater habitats) during certain period of their life and potamodromous (only freshwater inhabitants). Potamodromous species undertake migrations mainly because of the following reasons:

1. Spawning
2. Nurturing juveniles and larvae
3. Changes of habitats for different age groups
4. Migrations during environmental odds such as flood or catastrophic drift
5. Seasonal shifting of habitats

6. Foraging (feeding and nutrition) requirements through migrations
7. Migrations for dispersal

Migratory fishes can also be categorized based on the distance covered by them during migration as long, medium, and short distance, i.e., **>300, 30–300,** or **< 30 km,** respectively, in one direction per year (Waidbacher and Haidvogl 1998; Jungwirth et al. 2003).

3.1.4 Relevance of Population Ecology on Fish

Fishes characterized by streamlined body represent the most familiar and conspicuous aquatic vertebrates, so swift in their movement with full freedom within the waters however, this happy resident of the aquatic ecosystem are facing constrains in communicating among the networks of closely located water bodies as they are need of bridge of water to travel through. Such specialization have forced many fishes to remain locked to the habitats where their evolution took place as indigenous and endemic faunal component and adapted to withstand the challenges of inland living.

The diversity and species composition of the fish community vary considerably from the headwaters to the extreme downstream, in the estuarine part of the rivers before ending to the sea in tune with the continuous changes and fluctuation of so many hydrologic and geomorphic factors which the **pH**, alkalinity, temperature, dissolved oxygen, salinity, pressure gradients, intensity of current and velocity, texture, and nutrients status of the substrate. All those ecological parameters determine the numbers and geo-ecological properties of the habitats in a specific sector of in the rivers and streams. Fish species richness, an attribute of fish diversity tends to increase downstream with the decrease of the gradients and increase of the width and depth of the rivers. For small headwater streams, the gradient is found to be very steep in the small stream which experience fluctuations of environmental parameters with higher frequency and intensity resulting lowest species richness (Hynes 1970).

The reproductive success of fishes relying more on to the larval mortality than the fecundity (egg production potential) helps assessing the balance between reproductive stock size and recruitment which makes the fishery management process uncertain (Hjort 1914). The nature of the science has changed markedly since it first began to aggregate information on the vital statistics of exploited fish populations in the context of a logistic population growth model. The quest now is oriented very mechanistically.

The amount of attention given to the problem by fishery scientists, as with the more traditional population dynamics that preceded it, on occasion has caused me and perhaps others to assume that "**fish ecology**" is the recruitment–stock problem (Rothschild and Rooth 1982).

3.1.5 Relevance of Community Ecology on Fish

Interactions among species competition, predation, and symbiosis are the gist of the functional aspects of fish community ecology.

Prey–predator and competitive interactions were recognized as important driving force for shaping the community structure and function. Predation has many analogies with the human fishery experience (Stroud and Clepper 1979) and provides a natural topic for comparative study or application. Predators and fisheries are selective on the basis of species and size; predators and fisheries often overexploit their prey populations and alter the abundance and population structure of their preferred prey or targeted species; predators and fisheries alter the community structure of aquatic ecosystems by removal of key species; predators and fisheries have elements of an optimization of benefit–cost ratios; predators and fisheries produce a profit which contributes to fitness of fish or growth of an enterprise.

Owing to the rich data sets and analyses of exploitation in fisheries, ecologists interested in predation have much to gain by being familiar with the fishery literature and by interacting with fishery scientists. Long-term data collected by fishery agencies on fishing, intensity, and the abundance and distribution of fishes can be especially useful in analyses of predation. These relations could explain the variability in fish yields than did the abiotic factors. Ryder (1982) tried to have point out that both the strength and the weakness of this application of limnology to fishery science lies in the simplicity of the morphoedaphic index. The morphoedaphic index was developed in the fields of fishery and fishery management by way of meeting three major objectives: (**1**) to enable evaluation of the roles of abiotic factors on fish yield; (**2**) to help fisheries scientists, practitioners, and managers with a method for initial assessment of annual fish yield; and (**3**) to develop an understanding of the ground reality of the global of production processes in aquatic systems (Ryder 1982).

3.1.6 Ecosystem Ecology on Riverine Fish: Relevance of Habitat Diversity

Habitat diversity being the building block of biological diversity generate important values for conservation maintaining naturalness of the river by ensuring balances among water, energy and sediment budgets (Harper et al. 1997a). Understanding of habitat diversity holds direct bearings in the fishery science as it involves a range of eco-biological processes, for developing the provision for spawning (in the different textural gradients of the sediments; from the cobble–pebble to sands to silt–clay), for creating nursery grounds (breeding and nurturing of juveniles and fry in the assemblages of aquatic vegetation, their roots, and stems), for providing food and nutrients to all age groups of fish (within riffles and marginal vegetation), and forming a part of a rich diversity of habitats in order to meet the needs of a range of fish species and thereby evolving a balanced mixed fishery.

Interaction of abiotic factors such as water and soil quality parameters along with climatic, and morphometric factors on riverine fishes determines the morphoedaphic index (Ryder 1965) which can throw light with regard to the fish yields of a certain area of river and thereby enabling aquatic ecologists and fish managers to develop a conceptual foundation for the synthesis of biological production processes.

Besides, trophic interactions among different structural components of the river ecosystem, both living and nonliving ones, representing different trophic levels (microbes, phytoplankton, zooplankton, benthos, etc.) and continuous vertical and horizontal exchange of nutrients (allochthonous and autochthonous) within the rivers and adjoining ecosystems.

3.1.7 Landscape Ecology: Its Relevance on Fish

Landscape ecology focusing explicitly upon spatial pattern (Risser et al. (1984) considers the development, extent, dynamics, and management of spatial heterogeneity, spatial and temporal interactions across heterogeneous landscapes, and influences of spatial heterogeneity on biotic and abiotic processes. Regional ecology takes into consideration the ways and means of working of functioning of ecological systems incorporating land–water boundaries. The concept pertaining to the studies of island biogeography and eco-assessment tools for islands can also be applied to lakes and rivers, which, help predictions of the ecological behavior of fish assemblages along with their mode of seasonal distribution and thereby enable to be fishery managers to undertake proper management strategies. Regional ecology dealing with ecological interactions of an eco-region often incorporates land–water boundaries of rivers into the way ecological systems work.

3.2 Present Status of Freshwater Fish, Fisheries, and their Habitats

The second phase of twentieth century witnessed an imperative need for the protection and conservation of the freshwater habitats and their resources. The biodiversity convention at the United Nations Conference on Environment and Development (**UNCED**) has defined the term biodiversity, being a password across the globe as "**the variability among living organisms from all sources including inter alia, terrestrial, marine and other ecosystems and the ecological complexes of which they are part, this includes biodiversity within species, between species and of ecosystems**" (**UNCED** 1992). In that international convention, more popularly known as Rio-Conference, (1992) **167** countries signed on Biological Diversity

(**CBD**) with the prime objective of ensuring the conservation and sustainable use of biodiversity emphasizing on the equitable sharing of the benefits from utilizing genetic resources (Butchart et al. 2012; CBD 2010). Interactions within, between and among various levels of biodiversity forms the main intrinsic mechanism for self-sustenance of the structural and functional attributes of biodiversity in the temporal and spatial scales (Chakraborty 2003, 2013) and thereby to arrest and reduce the ongoing pace of biodiversity loss (Butchart et al. 2012; CBD 2010). The world conscience is now shifted from a mere mechanistic view to an ecological approach. Irrational exploitation of biodiversity has crossed the limits of sustainable levels resulting to the extermination of a number of species of plants and animals (Myers 1979). It is assumed that allowing the continuation of the present trend of exploitation may result the loss of many more species threatening the very existence of the entire ecosystem (Myers 1979).

Thus the eco-assessment, documentation, and conservation of biodiversity have become one of the major global environmental concerns. In accordance with the availability of different ecological niches and habitats in different water bodies, fishes have adapted themselves and are thriving well in their respective niches. Fishes exhibit enormous diversity in their habitats, morphology, and their biology (Chakraborty 2017).

It has been estimated that a growth rate of capture fisheries (**3.2%** per year) which was found far below the growth in aquaculture sectors (**9.6%** per year). This lower growth on capture fisheries, both at Global and National level (about **3.9%** per year) has necessitated to an urgent need for developing internationally acceptable common conservation strategies for aquatic biota along with their genetic diversity without disturbing the optimum requirements of human population and simultaneous ensuring of the equality between regions and generations (FAO, 2001, 2006).

Fisheries are in decline in most of the world's inland water bodies which are supposed to be due to multifarious and complex reasons which can be summed up as overfishing and environmental stresses (massive water abstraction, flood control measures, construction of dams, water pollution, introduction of exotic species, etc.). However, adoption of alternative holistic approach in the fisheries management can arrest such trend of declining of a precious bioresource bases. In such management practices, emphasis is laid on the manipulation and negotiation of the prevailing land and water qualities for the sustainable fisheries development alongside sharing with other users and stakeholders of the water resources. It is also possible to increase fish production through the culture of freshwater fishes with the help of research inputs in breeding and seed production, viable feed formulation and by implementing eco-friendly environmental management practices.

India is a vast country, endowed with commendable diversity of flora, fauna, and ecosystems (Chakraborty 2003). A fairly large higher number of hill streams, rivers, rivulets, other freshwater bodies such as lakes, reservoirs, irrigation channels, different form of wetlands, water runoff bodies, wayside ditches, etc. are present throughout India. Indian rivers carry a surface runoff of **167.23 mhm**, which is **5.6%** or **1/18th** of the total runoff flowing in all the rivers of the world (Jhingran 1991). India represents **4.4%** of global fish production, **10%** of global biodiversity and

1**.07%** of **G.D.P**. as a whole (FAO, 2001, 2006). Fish production in India today officially stands at **6.54** mmt, the production from inland sector being 3.4mmt of which freshwater aquaculture constitutes about **2.7** mmt, coastal aquaculture 0.1mmt while the rest comes from the rivers, reservoirs, and estuaries. However, this data pertaining to potential and quantity in respect of fish production leaves a large gap in respect of total fishery yield in order to meet the minimum nutritional requirement of the people (required production amount is **11 kg**. per capita as against the present production amount of **9 kg.** per capita (Tripathi, 2009). The need of the hour is to rise to the occasion in order to fulfill the targets set by the Government utilizing all the facilities and supports with an aim at achieving the goal in a sustainable way.

The fishery development, conservation, and management in freshwater bodies, especially rivers and adjoining water bodies require detailed baseline information pertaining to physicochemical, biological, and ecological attributes towards sustainability of fishery sectors. Most of such aquatic ecosystems such as riverine flow and basins, streams and rivulets, irrigation channels, bills, lakes, floodplains, etc. have either been lost, degraded or under severe degrees of environmental stresses because of multiple natural and anthropogenic factors operating over the decades. All these have led to cause water quality deterioration, putting stress on aquatic biodiversity and open up the scopes of livelihood generation. Welcomme and Halls (2004) has brought to the notice that how did such trend of alterations of natural hydrographs impart harmful effects on the freshwater fish assemblages in several corners of the world.

3.3 Ecological Relevance of Fish Habitats

Wetlands, both freshwater and brackish water, often referred to as nature's kidney and lungs provide a unique habitat for a wide variety of fisheries components. The extent of these resources are very impressive and command global attention mostly in the Gangetic and Brahmaputra basins in the states of Assam, Uttar Pradesh, Bihar, and West Bengal. The major rivers and their tributaries traverse through varied geoclimatic zones displaying high diversity in their biotic and abiotic characteristics throughout their linear drift.

In accordance with the availability of different ecological niches and habitats in different water bodies, fishes have adapted themselves and are thriving well in their respective niches. In India, the aquatic resources of the country include around **2.02 million km^2** area within the sea is marked as **Exclusive Economic Zone (EEZ)**, whereas total length of rivers is more or less **29,000 km**. The total length of all canals together is about **1,13,000 km**, whereas **1.75 million ha** of existing water is present as reservoirs. Around **1** million ha of water bodies occur within innumerable number of small and lentic water bodies such as tanks and ponds and about **0.6 million** ha area of water sheets remain as stagnant swampy and marshy water-spread areas. Therefore, highest yield through fish production from natural waters lend an assurance of a recurring, bountiful harvest of fishes in sustainable manner avoiding the damage of existing aquatic resources and maintaining the cost-effectiveness not wasting the financial investment, efforts, and energy for fishing in a developing country like India (Saravanan et al. 2003; Helfrich and Neves 2003; Weyand et al. 2005; Baird et al. 2009; Tripathi 2008).

3.4 Freshwater Fishery Resources in Asia

Asia accounts for **64%** of the global total of inland fisheries landings. China, India, Bangladesh, and Indonesia are the four most important inland fishery countries in the world, with Thailand ranking seventh. High catches in Asia reflect heavy exploitation of virtually all freshwaters, and capture fisheries based on wild stocks appear to be at or exceeding the limits of sustainable yield. Asia accounts for **64%** of the global total of inland fisheries landings (FAO, 2001, 2006).

High catches in Asia, mainly contributed by five countries viz .China, India, Bangladesh, Thailand and Indonesia reflect heavy exploitation of virtually all freshwaters, and capture fisheries based on wild stocks appear to be at or exceeding the limits of sustainable yield. Population declines began decades ago, and stocks have collapsed in recent years so that the fish is now endangered (FAO, 2001, 2006).

Increased availability and use of synthetic chemicals, rather than natural poisons (such as rotenone extracted from plants) may be a contributing factor also (Caldecott 1996). Motorboats and refrigeration technology allow the exploitation and marketing of previously inaccessible stocks. Unsustainable fishing practices, such as the use of ever-finer meshed nets and overfishing of spawning grounds, combined with the application of poisons, explosives, and electric shocking, have led to marked declines in major carp recruitment in the rivers.

The damage of such fishing practices cannot be separated from the effects of dams and fish kills caused by pollution (Liao et al. 1989). The synergism of anthropogenic impacts on the aquatic biota is exemplified by the Acipenseriformes (sturgeons and paddlefish) of the Yangtze River (Wei Q 1997). Acipenseriformes and other large fishes are very much especially vulnerable to overfishing and other environmental hazards because they require the long maturation time which limits rates of population recovery. This potamodromous species undertakes breeding migrations along (but within) the Yangtze River. Their populations have been dwindled to almost the level of an extinct species because the populations become stranded below the dam and cannot travel upstream to breed. Sedimentation (due largely to erosion from deforested uplands) has impacted the populations upstream of the dam. Both point (industrial source) and non-point pollution (domestic and agriculture sources) have degraded the habitat quality for sturgeons throughout the river, and overfishing has contributed to decline of both species. The same combination of factors has led to the decline of the anadromous Chinese paddlefish (*Psephurus gladius*: Polyodontidae) in the Yangtze River.

The Gezhouba Dam prevents access to upstream spawning sites, and this paddlefish (one of only two polyodontids on the planet) is likely to become extinct. Global warming-mediated climate change considerably influences the river discharge patterns and may have other effects that are likely to impact riverine biota in tropical Asia (and elsewhere). The determining roles of the volume and quantity of water cause harmful effects on the different stages in the life history of tropical fishes and other aquatic taxa which have appeared to be similar and parallel to the consequences of temperature stresses on the riverine fishes belonging to temperate regions (Dudgeon 2000; Meisner and Shuter 1992). Possible scenarios of climate change are revealed by the prevalence of wetter rainy seasons and continuous heat spells during hot summer seasons, with an increased frequency of extreme flow events. As fish catches (and secondary production) from rivers are positively correlated with the extent of inundated floodplain, the increased frequency of extreme flow events will increase the variability of fisheries yields. Detecting the onset of environmental degradation is problematic and may result in measures to reverse the situation being put in place only after population declines are generally not discernible early enough to permit appropriate remedial action (Figs. 3.2 and 3.3; Tables 3.1, 3.2, 3.3, 3.4, 3.5, and 3.6).

3.5 Fish as Tools for Rehabilitation: Habitat Heterogeneity vs Fish Diversity

Well-planned and methodical eco-assessments of the ecological effect on fish populations have now been used as an important tool for river rehabilitation. In such efforts, detailed geomorphological surveys tend to contribute important and pertinent information regarding the physical and hydraulic effects on the species composition and richness, diversity and seasonality of fish community of the riverine ecosystem to strengthen the process of rehabilitation. Restoration and rehabilitation approaches developing spatial and temporal heterogeneities by increasing the depth and flow heterogeneity across a range of scales of river which impart an inevitable effect upon its ecological functioning, and also enable fish species to find out more niche and thereby trigger both species diversity and richness as an positive outcome of the increased flow velocity in restored reaches (McCarthy 1985; Frissel et al. 1986; Townsend and Hildrew 1994; Poff 1997; Crook et al. 2001; Ward and Tockner 2001).

Therefore, use of physical responses to rehabilitation should not always be treated as a reliable predictor of ecological response. The weak response of fishes to rehabilitation efforts may have been because of the scale for low-gradient rivers and also for poor water quality within longer sections of eco-degraded river. In such context, more well-organized monitoring of fish diversity and distribution in the temporal and spatial scales help improved understanding in the designing of the eco-management with an emphasis on restoration schemes and also in identifying

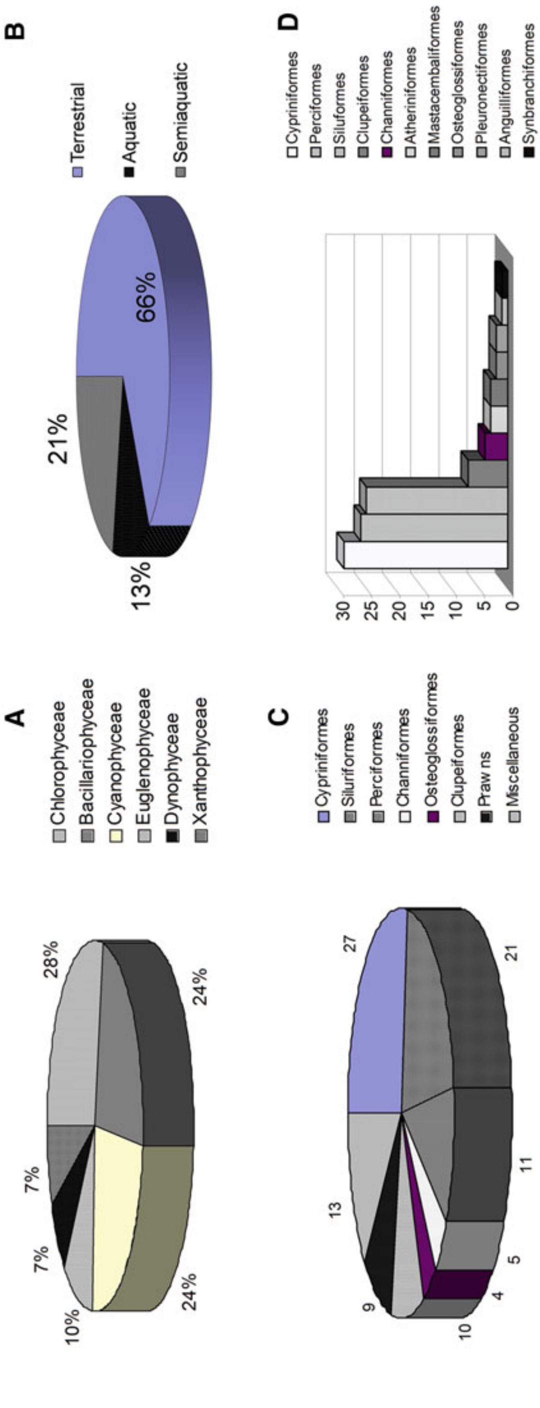

Fig. 3.2 Graphical representation of percentage of occurrence of different biodiversity components (**a**) Phytoplankton; (**b**) Macrophytes; (**c**) and (**d**) Fishes

Fig. 3.3 Pictorial representation of some freshwater fishes on their collection sites
(**A**) Large carp fishes(*Labeo* spp.), freshly collected from the Galudih Dam on Subarnarekha River
(**B**) Anadromous fishes (*Anguila* sp.) collected from Galudih Dam on Subarnarekha River
(**C**) Collection of fishes by a local boy by indigenous traditional method as gift of the nature from a small stream within the deep forest of Jharkhand state of India
(**D**) Fresh collection of small carp species (*Puntius* spp.) from the Dulung River, a tributaries of River Subarnarekha
(**E**) Very small harvest of minor carp species (*Labeo* bata) by a local boy from the lean flow of water of the Kansai River
(**F**) and (**G**) Collection of small fishes from the macrophytes based ecozones of riverine flows
(**G**), (**H**), and (**I**) Collection of small fishes from the dams and also flowing river water by operating of gill nets with the standardized innovative methods

and selecting suitable sites with greater potential for successful rehabilitation. An integration of physical mode of restoration alongside other management strategies such monitoring and maintaining of water quality to augment fish populations (Vickery et al. 2001; Benton et al. 2002; Robinson and Sutherland 2002). Similarly,

Table 3.1 Global fisheries production relying on freshwater in 2005

Type	Amount (thousand metric tons)	Values (million $ US)
Carps, barbells, and other cyprinids	20,500	18,800
Tilapias and other cichlids	2300	2800
Miscellaneous	4900	7900
Sturgeon, paddlefish	21	71
Rivers eels	266	1000
Salmon, trout, smelt	2143	9891
Freshwater crustaceans	1065	4715
Freshwater mollusks	154	91
Total	31,349	45,268

(FAO, 2001, 2006)

aquatic communities may be susceptible to changes in habitat diversity and quality along with their structural alterations. Furthermore, more reliance of the diversity and community interactions of fish along with their resilience to ecological disturbance are found to have enunciated from the habitat complexity (Gorman and Karr 1978; Schiemer et al. 1991; Pearsons et al. 1992).

Differential behavioral manifestations of fish in respect of their foraging preferences and abilities enable them to exploit a wide range of habitats within a river system, whereas some species exhibit distinct habitat preferences. For example, several ecological guilds of fishes are in need of different spawning substrata, where the nursery grounds provide them suitable habitats for the survivability of juveniles and larvae of fish (Mann 1996; Copp 1997; Cowx and Welcomme 1998).

Furthermore, habitat complexity puts an immense impact on the diversity of biotic constituents of fish community along with their resilience to disturbance (Gorman and Karr 1978; Schiemer et al. 1991; Copp 1997; Pearsons et al. 1992). Therefore, the loss of structural complexity and degradation of, in such context, deterioration of the quality and structure of habitats as nursery grounds for spawning and refuge habitats because of the ecological alteration of rivers and their flows cause tremendous harm to the very existence of fish fauna (Mann 1988; Swales 1989; Mason 1996).

Such modifications of the physical structure and related attributes of a river lead to develop spatial and temporal heterogeneities across a range of scales which determine fundamental characteristics and ecological functioning of river ecosystems (McCarthy 1985; Frissel et al. 1986; Townsend and Hildrew 1994; Poff 1997; Crook et al. 2001; Ward and Tockner 2001). Different fishes demonstrate varied form of abilities to exploit different strata of water column and bottom of river ecosystem, in accordance with their specific preferences of habitats resource partitioning and niche segregation. This has prompted different guilds of fishes to utilize a variety of spawning substrata in order to crucially ensure the survivability of fish larvae and juveniles upon the availability of nursery habitats (Mann 1996; Copp 1997; Cowx and Welcomme 1998). Several successful attempts have been made to artificially construct or create through manipulation of natural setups in the form of

Table 3.2 Some orders of fishes that have freshwater representatives

Order	Common name of freshwater species	Main region of dominance	Approximate number of freshwater species
Petromyzoniformes	Lampreys	Worldwide, coastal	40
Myliobatiformes	SRrays	Coastal	
Lepidosireniformes	Lungfishes	AF, SA	
Polypteriformes	Bichirs	AF	10
Acipenseriformes	Sturgeons, paddlefishes	PA, NA, AS	28
Lepisosteiformes	Gars	NA	7
Amiiformes	Bowfin	NA	1
Osteoglossiformes	Elephant fishes, Bony tongues	AF	200
Anguilliformes	Eels	Worldwide	26
Clupeiformes	Herrings, shads	Worldwide, some freshwater	80
Gonorynchiformes	Milkfishes	AF, AS	29
Cypriniformes	Minnows, carps, algae eaters, suckers, loaches	Worldwide	2600
Characiformes	Characins	SA, AF	1300
Siluriformes	Catfishes	Worldwide	2280
Gymnotiformes	Knifefishes	SA	62
Esociformes	Pikes, mudminnows	NA, PA	10
Osmeriformes	Smelts, galaxiids	Worldwide, AU	71
Salmoniformes	Salmon, trout, whitefishes, chars, graylings	NA, PA	66
Atheriniformes	Silversides, rainbow fishes, blue eyes	AU, AS	160
Beloniformes	Needlefishes, halfbeaks	AS	45
Cyprinodontiformes	Top minnows, killifishes, pupfishes	Worldwide	805
Synbranchiformes	Swamp eels, spiny eels	AF, AS, SA, US	87
Scorpaeniformes	Sculpins	NA, PA	62
Perciformes	Basses, perch, sunfishes, darters, cichlids, gobies, gouramis	Worldwide	2200

From Moyle and Cech (2000), Mathews (1998)

structurally simplified and hydraulically efficient river channels, which help in the rapid clearance of water from the floodplain (Brookes 1985; Smith et al. 1990; Wilcock and Essery 1991; Hodgson and O'Hara 1994).The alteration of river flows because of such river channelization have imposed distinct impacts in determining fish assemblages and distribution of fish along with other aquatic organisms (Mann 1988; Swales 1989). Moreover, such impacts have been observed to become

Table 3.3 Diversity of Ichthyofauna in different rivers and river-associated water bodies in South West Bengal, India (Mishra et al. 2003)

Order-1: Osteoglossiformes Family-1: Notopteridae Genus-1: *Chitala* (Hamilton) 1.*Chitala chitala* (Hamilton-Buchanan) Genus-2: *Notopterus* (Lacepede) 2. *Notopterus notopterus* (Pallas) Order-2: Anguilliformes Family-2: Anguillidae Genus-3: *Anguilla* (Schrank) 3. *Anguilla bengalensis bengalensis* (Gray and Hardwicke) Order-3: Clupeiformes Family-3: Clupeidae Genus-4 *Gudusia* (Fowler) 4. *Gudusia chapra* (Hamilton-Buchanan) Genus-5: *Hilsa* Regan. 5. *Tenualosa ilisha* (Hamilton-Buchanan) Genus-6: *Escualosa* (Whitley) 6. *Escualosa thoracata* (Valenciennes) Family-4: Engraulididae Genus-7: *Thryssa* (Cuvier) 7.*Thryssa hamiltonii* (Gray) Genus-8: *Setipinna* (Swainson) 8. *Setipinna taty* (Valenciennes) 9. *Setipinna phasa* (Hamilton-Buchanan) Genus-9: *Coilia* (Gray) 10. *Coilia ramacarati* (Hamilton-Buchanan) Order-4: Channiformes Family-5: Channidae Genus-10: *Channa* (Scopoli) 11. *Channa orientalis* (Bloch and Schneider) 12. *Channa punctatus* (Bloch) 13. *Channa stewartii* (Playfair) 14. *Channa striatus* (Bloch) Order-5: Synbranchiformes Family-6: Synbranchidae Genus-11: *Monopterus* (Lacepede) 15. *Monopterus cuchia* (Hamilton-Buchanan) Order-6: Cypriniformes Family-7: Cyprinidae Genus-12: *Chela* (Hamilton) 16. *Chela cachius* (Hamilton-Buchanan) Genus-13: *Securicula* (Gunther) 17. *Securicula gora* (Hamilton-Buchanan)	Genus-14: *Salmostoma* (Swainson) 18. *Salmostoma bacaila* (Hamilton-Buchanan) 19. *Salmostoma phulo phulo* (Hamilton-Buchanan) Genus-15: *Esomus* (Swainson) 20. *Esomus danricus* (Hamilton-Buchanan) Genus-16: *Danio* (Hamilton-Buchanan) 21. *Danio rerio* (Hamilton-Buchanan) 22. *Danio aequipinnatus* (McClelland) Genus-17: *Amblypharyngodon* (Bleeker) 23. *Amblypharyngodon mola* (Hamilton-Buchanan) Genus-18: *Barilius* (Hamilton-Buchanan) 24. *Barilius bendelisis* (Hamilton-Buchanan) 25. *Barilius barna* (Hamilton-Buchanan) Genus-19: *Puntius* (Hamilton-Buchanan) 26. *Puntius sophore* (Hamilton-Buchanan) 27. *Puntius ticto* (Hamilton-Buchanan) 28. *Puntius chola* (Hamilton-Buchanan) 29. *Puntius sarana sarana* (Hamilton-Buchanan) 30. *Puntius conchonius* (Hamilton-Buchanan). Genus-20: *Osteobrama* (Heckel) 31. *Osteobrama cotio cotio* (Hamilton-Buchanan). Genus-21: *Labeo* (Cuvier) 32. *Labeo boga* (Hamilton-Buchanan) 33. *Labeo bata* (Hamilton-Buchanan) 34. *Labeo calbasu* (Hamilton-Buchanan) 35. *Labeo rohita* (Hamilton-Buchanan) 36. *Labeo dero* (Hamilton-Buchanan) Genus-22: *Chagunius* (Smith) 37. *Chagunius chagunio* (Hamilton-Buchanan) Genus-23: *Cirrhinus* (Cuvier) 38. *Cirrhinus mrigala mrigala* (Hamilton-Buchanan) Genus-24: *Catla* (Valenciennes) 39. *Catla catla* (Hamilton-Buchanan) Genus-25: *Crossocheilus* (Kuhlet van Hasselt) 40. *Crossocheilus latius latius* (Hamilton-Buchanan) Family-8: Cobitidae Genus-26: *Noemacheilus* (Van Hasselt) 41. *Noemacheilus botia* (Hamilton-Buchanan) Genus-27: *Botia* (Gray)

(continued)

Table 3.3 (continued)

	42. *Botia birdi* (Chaudhuri). Genus-28: *Lepidocephalus* (Bleeker) 43. *Lepidocephalus guntia* (Hamilton-Buchanan) Genus-29: *Garra* (Hamilton-Buchanan) 44. *Garra mullya* (Sykes)
Order-7: Siluriformes Family-9: Bagridae Genus-30: Rita (Bleeker) 45. *Rita rita* (Hamilton-Buchanan) Genus-31. Batasio (Blyth) 46. *Batasio batasio* (Hamilton-Buchanan) Genus-32: Mystus (Scopoli) 47. *Mystus bleekeri* (Day) 48. *Mystus cavasius* (Hamilton-Buchanan) 49. *Mystus gulio* (Hamilton-Buchanan) 50. *Mystus vittatus* (Bloch) Genus-33: Aorichthys (Wu) 51. *Aorichthys aor* (Hamilton-Buchanan) 52. *Aorichthys seenghala* (Sykes) Family-10: Siluridae Genus-34: Ompok (Lacepede) 53. *Ompok bimaculatus* (Bloch) 54. *Ompok pabda* (Hamilton-Buchanan) 55. *Ompok pabo* (Hamilton-Buchanan) Genus-35: Wallago (Bleeker) 56. *Wallago attu* (Schneider) Genus-36: Ailia (Gray) 57. *Ailia coila* (Hamilton-Buchanan) Genus-37: Pseudeutropius (Bleeker) 58. *Pseudeutropius atherinoides* (Bloch) Genus-38: Clupisoma (Swainson) 59. *Clupisoma garua* (Hamilton-Buchanan) Genus-39: Eutropiichthys (Bleeker) 60. *Eutropiichthys vacha* (Hamilton-Buchanan) Family-11: Pangasiidae Genus-40: Pangasius (Valenciennes) 61. *Pangasius pangasius* (Hamilton-Buchanan) Family-12: Sisoridae Genus-41: Gagata (Bleeker) 62. *Gagata cenia* (Hamilton-Buchanan) Genus-42: Bagarius (Bleeker) 63. *Bagarius bagarius* (Hamilton-Buchanan) Genus-43: Nangra (Day) 64. *Nangra viridescens* (Hamilton-Buchanan)	Genus-44: Erethistes (Mullar and Troschel) 65. Erethistes pussilus Muller-Troschel Family-13: Clariidae Genus-45: Clarias (Scopoli) 66. *Clarias batrachus* (Linnaeus) Family-14: Heteropneustidae Genus-46: Heteropneustes (Muller) 67. *Heteropneustes fossilis* (Bloch) Family-15: Ariidae Genus-47: Arius (Valenciennes) 68. *Arius gagora* (Hamilton-Buchanan) 69. *Arius platystomus* (Day) Order-8: Atheriniformes Family-16: Belonidae Genus-48: Xenetodon (Regan) 70. Xenetodon cancila (Hamilton-Buchanan) Family-17: Cyprinodontidae Genus-49: Aplocheilus (McClelland) 71. *Aplocheilus panchax* (Hamilton-Buchanan) Genus-50: Oryzias (Jordan and Snyder) 72. *Oryzias melanostigma* (McClelland) Order-9: Perciformes Family-18: Centropomidae Genus-51: Lates (Cuvier) 73. *Lates calcarifer* (Bloch) Family-19: Ambassidae Genus-52: Chanda (Hamilton-Buchanan) 74. *Chanda nama* (Hamilton-Buchanan) Genus-53: Pseudambassis (Bleeker) 75. *Pseudambassis ranga* (Hamilton-Buchanan) Family-20: Nandidae Genus-54: Badis (Bleeker) 76. *Badis badis* (Hamilton-Buchanan) Genus-55: Nandus (Valenciennes) 77. *Nandus nandus* (Hamilton-Buchanan) Family-21: Mugilidae Genus-56: Rhinomugil (Gill) 78. *Rhinomugil corsula* (Hamilton-Buchanan)

(continued)

Table 3.3 (continued)

Order-7: Siluriformes Family-9: Bagridae Genus-30: *Rita* (Bleeker) 45. *Rita rita* (Hamilton-Buchanan) Genus-31. *Batasio* (Blyth) 46. *Batasio batasio* (Hamilton-Buchanan) Genus-32: *Mystus* (Scopoli) 47. *Mystus bleekeri* (Day). 48. *Mystus cavasius* (Hamilton-Buchanan) 49. *Mystus gulio* (Hamilton-Buchanan) 50. *Mystus vittatus* (Bloch) Genus-33: *Aorichthys* (Wu) 51. *Aorichthys aor* (Hamilton-Buchanan) 52. *Aorichthys seenghala* (Sykes) Family-10: Siluridae Genus-34: *Ompok* (Lacepede) 53. *Ompok bimaculatus* (Bloch) 54. *Ompok pabda* (Hamilton-Buchanan) 55. *Ompok pabo* (Hamilton-Buchanan) Genus-35: *Wallago* (Bleeker) 56. *Wallago attu* (Schneider) Genus-36: *Ailia* (Gray) 57. *Ailia coila* (Hamilton-Buchanan) Genus-37: *Pseudeutropius* (Bleeker) 58. *Pseudeutropius atherinoides* (Bloch) Genus-38: *Clupisoma* (Swainson) 59. *Clupisoma garua* (Hamilton-Buchanan) Genus-39: *Eutropiichthys* (Bleeker) 60. *Eutropiichthys vacha* (Hamilton-Buchanan) Family-11: Pangasiidae Genus-40: *Pangasius* (Valenciennes) 61. *Pangasius pangasius* (Hamilton-Buchanan) Family-12: Sisoridae Genus-41: *Gagata* (Bleeker) 62. *Gagata cenia* (Hamilton-Buchanan) Genus-42: *Bagarius* (Bleeker) 63. *Bagarius bagarius* (Hamilton-Buchanan) Genus-43: *Nangra* (Day) 64. *Nangra viridescens* (Hamilton-Buchanan)	Genus-44: *Erethistes* (Mullar and Troschel) 65. *Erethistes pussilus* (Muller-Troschel) Family-13: Clariidae Genus-45: *Clarias* (Scopoli) 66. *Clarias batrachus* (Linnaeus) Family-14: Heteropneustidae Genus-46: *Heteropneustes* (Muller) 67. *Heteropneustes fossilis* (Bloch) Family-15: Ariidae Genus-47: *Arius* (Valenciennes) 68. *Arius gagora* (Hamilton-Buchanan) 69. *Arius platystomus* (Day) **Order-8: Atheriniformes** Family-16: Belonidae Genus-48: *Xenetodon* (Regan) 70. *Xenetodon cancila* (Hamilton-Buchanan) Family-17: Cyprinodontidae Genus-49: *Aplocheilus* (McClelland) 71. *Aplocheilus panchax* (Hamilton-Buchanan) Genus-50: *Oryzias* (Jordan and Snyder) 72. *Oryzias melanostigma* (McClelland) **Order-9: Perciformes** Family-18: Centropomidae Genus-51: *Lates* (Cuvier) 73. *Lates calcarifer* (Bloch) Family-19: Ambassidae Genus-52: *Chanda* (Hamilton-Buchanan) 74. *Chanda nama* (Hamilton-Buchanan) Genus-53: *Pseudambassis* (Bleeker) 75. *Pseudambassis ranga* (Hamilton-Buchanan) Family-20: Nandidae Genus-54: *Badis* (Bleeker) 76. *Badis badis* (Hamilton-Buchanan) Genus-55: *Nandus* (Valenciennes) 77. *Nandus nandus* (Hamilton-Buchanan) Family-21: Mugilidae Genus-56: *Rhinomugil* (Gill) 78. *Rhinomugil corsula* (Hamilton-Buchanan)
Genus-57: *Mugil* (Linnaeus) 79. *Mugil cephalus* (Linnaeus) Genus-58: *Liza* (Jordan and Swain) 80. *Liza parsia* (Hamilton-Buchanan) 81. *Liza tade* (Forskal) Family-22: Polynemidae Genus-59: *Polynemus* (Linnaeus) 82. *Polynemus paradiseus* (Linnaeus) Genus-60: *Eleutheronema* (Bleeker) 83. *Eleutheronema tetradactylum* (Shaw)	Family-27: Eleotridae Genus-67: *Eleotris* (Schneider) 92. *Eleotris fusca* (Schneider) Family-28: Gobioididae Genus-68: *Odontamblyopus* (Bleeker) 93. *Odontamblyopus rubicundus* (Hamilton-Buchanan) Family-29: Sillaginidae Genus-69: *Sillaginopsis* (Gill) 94. *Sillaginopsis panijus* (Hamilton-

(continued)

Table 3.3 (continued)

Family-23: Gobiidae Genus-61: *Glossogobius* (Gill) 84. *Glossogobius giuris* (Hamilton-Buchanan) Genus-62: *Pseudapocryptes* (Bleeker) 85. *Pseudapocryptes lanceolatus* (Bloch-Schneider) Genus-63: *Apocryptes* (Val) 86. *Apocryptes macrolepis* (Bleeker) 87. *Apocryptes cantoris* (Day) Family-24: Anabantidae Genus-64: *Anabas* (Cuvier and Cloquet) 88. *Anabas cobojius* (Hamilton-Buchanan) 89. *Anabas testudineus* (Bloch) Family-25: Belontidae Genus-65: *Polyacanthus* (Cuvier) 90. *Polyacanthus fasciatus* (Schneider) Family-26: Teraponidae Genus-66: *Terapon* (Cuvier) 91. *Terapon jarbua* (Forsskal)	Buchanan) Family-30: Sciaenidae Genus-70: *Pama* (Fowler) 95. *Pama pama* (Hamilton-Buchanan) Genus-71: *Panna* (Mohan) 96. *Panna microdon* (Bleeker) Genus-72: *Nibea* 97. *Nibea soldado* (Lacepede) Genus-73: *Otolithoides* (Fowler) 98. *Otolithoides biauritus* (Cantor) **Order-10: Mastacembeliformes** Family-31: Mastacembelidae Genus-74: *Mastacembelus* (Scopoli) 99. *Mastacembelus armatus* (Lacepede) Genus-75: *Macrognathus* (Lacepede) 100. *Macrognathus pancalus* (Hamilton-Buchanan). 101. *Macrognathus aral* (Bloch and Schneider). **Order-11: Pleuronectiformes** Family-32: Cynoglossidae Genus-76: *Cynoglossus* (Hamilton-Buchanan) 102. *Cynoglossus lingua* (Hamilton-Buchanan) 103. *Cynoglossus puncticeps* (Richardson)

aggravated because of deterioration of water quality by the runoff from intensified agriculture (Mason 1996).

3.6 Prerequisites for a Fish Fauna to Enhance the Density or Richness

Aquatic biotic components are endowed with the natural resilient power to overcome ecological alteration-mediated disturbances and also to recover the old stocks on getting proper supports through the rehabilitation of degraded habitats (Giller and Myers, 1996). However, the positive responses of fish and their community to the ecological improvement followed by habitat improvement depend, firstly, in tune with the improvement of water quality and, secondly, more availability both in respect of volume and depth to cater to the needs of existing populations to disperse and to exploit, different niches of improved habitat. The similar scientific interpretations can also be applied for the other invertebrates of river ecosystem which have revealed the slower the recovery rate because of partial and isolated rehabilitation efforts (Fuchs and Statzner 1990; Hansen et al. 1999).

Table 3.4 Ichthyofauna inhabiting both in freshwater and saline water bodies (Mishra et al. 2003)

Sl. No	Species	Nature of species
1.	*Hilsa* (*Tenualosa*) ilisha	Migratory
2.	*Escualosa thoracata*	Coastal pelagic
3.	*Thryssa hamiltonii*	Coastal pelagic
4.	*Setipinna taty*	Coastal pelagic
5.	*Setipinna phasa*	Coastal pelagic
6.	*Coilia ramacarati*	Coastal
7.	*Mystus gulio*	Estuarine
8.	*Arius gagora*	Estuarine
9.	*Arius platystomus*	Estuarine
10.	*Lates calcarifer*	Estuarine
11.	*Mugil cephalus*	Estuarine
12.	*Liza parsia*	Estuarine
13.	*Liza tade*	Estuarine
14.	*Polynumus paradiseus*	Estuarine
15.	*Eleutheronema*	Pelagic
16.	*Pseudapocryptes lanceolatus*	Coastal pelagic
17.	*Apocryptes macrolepis*	Coastal pelagic
18.	*Apocryptes cantoris*	Coastal pelagic
19.	*Terapon jarbua*	Coastal pelagic
20.	*Eleotris fusca*	Estuarine
21.	*Odontamblyopus rubicundus*	Estuarine
22.	*Sillaginopsis panijus*	Estuarine
23.	*Pama pama*	Estuarine
24.	*Panna microdon*	Estuarine
25.	*Otolithoides biauritus*	Estuarine
26.	*Cynoglossus lingua*	Estuarine
27.	*Cynoglossus punticeps*	Estuarine
28.	*Anguilla bengalensis*	Pelagic
29.	*Monopterus cuchia*	Pelagic

However, such resilience of fish assemblages against environmental perturbations depends, firstly, on the availability of permissible levels of water quality parameters help developing a higher diversity of fish and, secondly, potential of existing populations to disperse and utilize the rehabilitated habitats through resource partitioning and niche segregation (Fuchs and Statzner 1990; Hansen et al. 1999).

3.6.1 Different Forms of Diversity: Emphasis on β Diversity

Different compositional heterogeneities within the river habitats seldom relate to each other in a predictable manner and can be explained with the concept of beta

Table 3.5 Different conservation categories of fishes as recorded from the Subarnarekha River of South West Bengal, India (Mishra et al. 2017)

Name of the species	Critically endangered	Endangered	Vulnerable	Lower risk near threatened	Lower risk least concern
Family Notopteridae					
Notopterus notopterus (palles)				+	
Family Anguillidae					
Anguilla bengalensis (Gray)		+			
Family Cyprinidae					
Subfamily Danioninae (=Rasborinae)					
Salmostoma bacaila (Hamilton-Buchanan)					+
Subfamily Rasborinae					
Amblypharyngodon mola (Hamilton-Buchanan)					+
Aspidoparia morar (Hamilton-Buchanan)				+	
Barilius barila (Hamilton-Buchanan)			+		
Barilius barna (Hamilton-Buchanan)				+	
Barilius bendelisis (Hamilton-Buchanan)				+	
Esomus danricus (Hamilton-Buchanan)					+
Rasbora daniconius (Hamilton-Buchanan)				+	
Subfamily Cyprininae					
Cirrhinus reba (Hamilton-Buchanan)			+		
Labeo angra (Hamilton-Buchanan)				+	
Labeo pangusia (Hamilton-Buchanan)				+	
Osteobrama cotio (Hamilton-Buchanan)				+	
Puntius chola (Hamilton-Buchanan)			+		
Puntius conchonius (Hamilton-Buchanan)			+		
Puntius sarana sarana (Hamilton-Buchanan)			+		

(continued)

Table 3.5 (continued)

Name of the species	Critically endangered	Endangered	Vulnerable	Lower risk near threatened	Lower risk least concern
Puntius sophore (Hamilton-Buchanan)				+	
Purtius ticto (Hamilton-Buchanan)				+	
Subfamily Grrinae					
Garra gotyla gotyla (Gray)			+		
Family Balitoridae					
Subfamily Noemacheilinae					
*Acanthocobitis boti*a (Hamilton-Buchanan)				+	
Family BAGRIDAE					
Mystus bleekeri (Day)			+		
Mystus cavasius (Hamilton-Buchanan)				+	
Neotropius atherinoides (Bloch)		+			
Family Amblycipitidae				+	
Amblyceps mangois (Hamilton-Buchanan)					
Family Sisoridae			+		
Bagarius bagarius (Hamilton-Buchanan)		+			
Glyptothorax nelson (Ganguly, Datta, and Sen)		+			
Glyptothorax saisii (Jenkins)				+	
Laguvia ribeiroi (Hora)				+	
Gogangra viridescens (Ham-Buch)					
Family Schilbeidae			+		
Clupisoma garua (Hamilton-Buchanan)					
Family Pangasiidae	+				
Pangasius pangasius (Hamilton-Buchanan)					
Family Heteropnuestidae			+		
Heteropneustes fossilis (Bloch)					
Family Clariidae			+		

(continued)

Table 3.5 (continued)

Name of the species	Critically endangered	Endangered	Vulnerable	Lower risk near threatened	Lower risk least concern
Clarius batrachus (Linnaeus)					
Family Belonidae				+	
Xenentodon cancila (Hamilton-Buchanan)					
Family Mugilidae			+		
Rhinomugil corsula (Hamilton-Buchanan)					
Family Gobiidae				+	
Glossogobius giuris (Hamilton-Buchanan)					
Family Anabantidae			+		
Anabas cobojius (Hamilton-Buchanan)					
Family Belontidae				+	
Colisa fasciatus (Schneider)					
Family Channidae			+		
Channa orientalis					
Family Mastacembelidae				+	
M. pancalus (Hamilton-Buchanan)					

Conservation categories, number in parenthesis
Vulnerable – (14); Lower Risk Near Threatened – (20); Lower Risk Least Concern – (3); Data Deficient – (2)

diversity (**β** diversity) referring to a wide variety of phenomena which is derived from multiplicatively partitioned effective number of species.

The **β** diversity encompasses even most important attributes:

1. Regional-to-local diversity ratio
2. Two-way diversity ratio
3. Absolute effective species turnover (= regional diversity excess)
4. Whittaker's effective species turnover
5. Proportional effective species turnover
6. Regional entropy excess
7. Regional variance excess

Whittaker (1960) defined beta (**β**) diversity as "**The, extent and degree of differentiations of community composition in accordance with the complex-gradient of ecological patterns and changes within the environment**." Beta diversity can be quantified as the ratio of gamma (**γ**) diversity (diversity in a set of

Table 3.6 Six functional measures (in 25 subcategories) for fish species. All measures are categorical variables with the exception of the morphology, which is continuous

Trophic guild
1. Herbivore–detritivore
2. Omnivore
3. General invertivore
4. Surface/water-column invertivore
5. Benthic invertivore
6. Piscivore*
7. Planktivore
8. Parasite
Habitat classification
Stream size preference
1. Small
2. Medium–large
3. Small–large
4. Lentic
Current velocity preference
1. Fast
2. Moderate
3. Slow–none
4. General
Substratum preference
1. Rubble (rocky, gravel)
2. Sand
3. Silt
4. General
Tolerance
1. High
2. Medium
3. Low
Body morphology
1. Swimming factor
2. Shape factor

sampling units) to alpha (**α**) diversity (average diversity within sampling units) within each geological formation.

Cody (1975) also defined beta diversity (**β** diversity) as the rate of turnover of the species composition along an ecological gradient within one geographical region, and gamma diversity (**γ** diversity) as the rate of compositional turnover with geographical distance within one habitat. Bratton (1975) also used the term beta diversity to refer to the rate of species turnover along a gradient.

Whittaker (1977) also proposed a hierarchical nomenclature pertaining to different diversities where alpha diversity is considered as the diversity within a habitat; beta diversity refers to the differentiation of species composition among habitats in a landscape; gamma diversity takes into consideration of such differentiation of species to total within landscape diversity; delta diversity focuses changes of species composition among landscapes of a region; and epsilon diversity points out total within-region diversity.

3.7 Impact of Habitat Fragmentation on Fish Biodiversity: A Cause of Extinction

Land-use change, which often results in habitat fragmentation, conversion, or degradation, is one of the global anthropogenic causes of past and projected loss of species (Kareiva et al. 1993; Sala et al. 2000). The main consequence of habitat fragmentation is the subdivision of a population into several smaller units. Theory predicts that the smaller the size of a population, the higher the probability of its extinction (Lande 1993).

Thus small populations occupying small fragments may be faced with a high risk of extinction over relatively short, ecological time scales unless they are rescued by immigration. Quantifying the relationship between fragment size and extinction probability is of major importance for predicting the consequences of ongoing and future trends of habitat fragmentation of riverine habitats due to human activities, particularly for species that have a low dispersal ability.

The faunal relaxation approach, pioneered by Diamond (1972), is probably the method that has most frequently been used to indirectly estimate extinction rates. The basic idea of this approach was to compare extant species richness per island with richness predicted at the time of fragmentation. According to the theory of island biogeography, species richness per island should decrease after fragmentation because of the disruption, blockage, reduction, and stoppage of immigration which is designated as stopped or reduced. This process is known as faunal relaxation (Diamond 1972).

If speciation and colonization are negligible, then temporal change in richness is mainly the result of extinctions. Using a similar framework, other systems that were fragmented during the climate change that ended the last glacial period have served as empirical models of the consequences of fragmentation for species richness (Brown 1971; Case 1975; Wilcox 1978; Heaney et al. 1986; Lawlor 1986; Patterson and Atmar 1986; Richman et al. 1988; Lomolino et al. 1989; Foufopoulos and Ives 1999). To anticipate the erosion of biodiversity within this highly vulnerable group. A scientific understanding of the contribution of natural and human drivers of population extinction is needed in order to anticipate and assess the trend of erosion of fish diversity especially within the highly vulnerable group which is supposed to throw light on the probable ecological factors and processes associated with extinction process. Whereas the negative impacts of habitat fragmentation (dams) within the main river beds and also associated water ways on many aspects of fish biology and ecology (Fukushima et al. 2001) are clearly identified, few including empirical estimates of population extinction rates due to such existing fragmentation exist

(Morita and Yamamoto 2002). Establishing an empirical relationship between surface area occupied by a population and extinction rate is a first step towards a better prediction of the impact of habitat fragmentation on future river fish biodiversity loss (Figs. 3.2 and 3.3).

3.8 Spatial and Temporal Heterogeneity: Relationship with Guilds of Fishes

Habitat heterogeneities across a range of spatial and temporal scales fundamentally determine the species assemblages, diversity, trophic interactions, and distribution of biotic components in tune with the changing abiotic parameters of aquatic ecosystems (Frissel et al. 1986; Townsend and Hildrew 1994; Poff 1997; Crook et al. 2001; Ward and Tockner 2001). Different adult fishes are in need of a wide range of habitats and different guilds of fishes exhibit their own preferences for habitats in order to meet the requirements for their spawning, whereas the survival strategies of larvae and juveniles of fish are connected with the availability of nursery habitats (Mann 1996; Copp 1997; Cowx and Welcomme 1998).

Furthermore, the structure of the fish community and their ability to tolerate different ecological disturbances must have close approximation with habitat complexity (Gorman and Karr 1978; Schiemer et al. 1991; Pearsons et al. 1992). Therefore, the modification and deviation from natural structural complexity leading to the eco-degradation of spawning, nursery and refuge habitats due to ecological perturbations in the river ecosystems might cause deleterious effects on fish fauna. This is evident from several research documentations on the negative impacts of river channelization in causing changes in fish assemblages in several rivers of England (Spillet et al. 1985; Cowx et al. 1986; Mann 1988; Swales 1989; Swales et al. 1988; Punchard et al. 2000).

Intensification of agriculture since the early periods of twentieth century has caused considerable alterations in the water quality of rivers resulting the loss of aquatic species (Mason 1996). Similar trend of decline of fish diversity have also been recorded by a series of research investigations from warm water rivers in North America (Chapman and Knudsen 1980; Edwards et al. 1984; Portt et al. 1986) and rivers in Northern Europe (Jungwirth et al. 1993; Muotka and Laasonen 2002.

Several rehabilitation strategies as pre-steps of river restoration programs have been undertaken for reducing pollution (Moss 1988; Axford 1994) and diversifying river habitats (Swales 1989; Hey 1992). In several rivers, natural eco-geological processes such as sediment transport, erosion, and deposition have resulted reformation of different geomorphological structures like riffles and pools as a consequence of channel modification (Brookes 1985, 1992; Hey 1992). However, in low-gradient rivers with insufficient stream power required for carrying, transporting, and depositing river bed sediments do not show such natural geomorphological formations. Based on such baseline information, different river rehabilitation projects have been undertaken at different parts of England with new techniques, such as remeandering and narrowing of channelized reaches, reprofiling of banks with enhanced steepness, and artificially developing riffles and backwaters based on natural geo-ecological processes (Cowx and Welcomme 1998; RRC 1999). All those efforts have resulted a conducive physical and hydraulic ecological condition within river ecosystems for the growth and propagation of fish and other organisms (Holmes 1998). The extent and scale of all those rehabilitation projects differed from one another. Large-scale river rehabilitation projects involve an area extending from a few to several kilometers with the involvement and application of several rehabilitation techniques with an expenditure of a large amount of money (Biggs et al. 1998; Kronvang et al. 1998).

3.8.1 River Continuum Concept vs Ecological Guilds of Fish

The River Continuum Concept is stating the continuous changing patterns of the river ecosystem from the point its origin to the end which occurs mainly because of the changes of the geohydrology and the quantum of energy inputs. In the upstream, the shapes and sizes of the rivers remain very small and narrow with fast-flowing water and shaded riparian vegetation. Most of the energy enter into the rivers from the decomposing products of the riparian forests as allochthonous nutrients. This concept also predicts a longitudinal gradient with regard to the structure and functioning of rivers relative to fish assemblage trophic structure and distribution of biomass among feeding guilds of fishes which were classified as detritivores, herbivores, invertivores, piscivores, or planktivores. The diversity, abundances, and biomass of all feeding guilds showed an increasing trend from upstream catchment area towards downstream direction. Moreover, out of five distinct guilds, herbivores and planktivores fish populations dominate in respect of higher percentage of biomass and diversity within the fish community in upstream catchment areas, whereas the fish guilds with detritivores, invertivores, and piscivores feeding habits started dominating the fish assemblages at the midstream and downstream characterized by a transformation from lotic into lentic systems promoting increasing inputs of autochthonous nutrients though higher primary production.

The physical and chemical gradients of the rivers dictate the structure and function of biotic communities in lotic systems. These facts are substantiated by the river continuum concept (**RCC**) (Vannote et al. 1980) that predicts longitudinal gradients relative to the importance and shifts of different sources of energy for biological productivity (allochthonous, and autochthonous) along the gradient, which in turn control the species composition, diversity and density and mode of community composition and interactions in river ecosystem (Vannote et al. 1980; Sedell et al. 1989). In the upper reaches, biotic communities are expected to depend primarily on allochthonous sources of energy contributed by riparian flora and fauna, therefore supporting a community with coarse particulate organic matter as a basal resource where macroinvertebrate shredders and collectors predominate. In contrast, biotic communities in lower reaches rely more on autochthonous sources of energy produced directly in the river channel or flowing downstream from upper reaches, and there is a resulting shift to macroinvertebrate communities dominated by grazers and collectors (Vannote et al. 1980; Johnson et al. 1995).

Although formulation of the **RCC** was focused on changes in the macroinvertebrate community, fish assemblages are also expected to follow predictable longitudinal patterns influenced by physical gradients and resource availability. Invertivores predominate in the headwaters (Oberdorff and Porcher 1992; Oberdorff et al. 1993; McGarvey and Hughes 2008), where invertebrates are the main food resource for fish (Lotrich 1973; Angermeier and Karr 1983). A transition to detritivore-and-herbivore-dominated communities follows the increase in autochthonous resources in middle and lower reaches (Angermeier and Karr 1983; Ibanez et al. 2007); and piscivores increase in proportion and richness downstream, as vertical and horizontal foraging space increases (Oberdoff et al. 1993; Ibanez et al. 2007; McGarvey and Hughes 2008).

In addition, planktivores fishes show their preference to inhabit in semi-lentic part of the rivers and occur in higher numbers in stream order, reflecting this kind of ecological setups (Vannote et al. 1980). This observation is almost similar to that of invertivores which predominate in upper reaches with an increased availability of large, coarser particulate food materials. Based on all these findings, it can be hypothesized that trophic structure of the fish assemblage is linked to the diversity of habitats and trophic resources along the river continuum displaying varied form of feeding guilds. However, it can also be hypothesized that the composition of feeding guilds along the longitudinal gradients of river cascade, displaying alternative pattern do not always precisely follow predictions as outlined by the **RCC** because of the drastic transformation of river habitats and specific changes in ecodynamics of river caused by a multitude of ecological and meteorological factors.

3.9 Terminologies Pertaining to Eco-Evolutionary Perspectives

3.9.1 Life History Polymorphism

Trophic polymorphism of fish refers to that condition of existence of different (two or more than two) functional traits for feeding within the same population of a fish species. As fishes being the potential keystone predators in an aquatic ecosystem usually display intense impacts on prey communities, the phenotypic divergence of their feeding traits can change both biotic and abiotic factors of river ecosystems through the alteration of trophic dynamics.

In freshwater fishes, another example of phenotypic polymorphism is often found in life history traits. In many species of salmon and sticklebacks in which trophic polymorphism is well-known, two different life history forms coexist within a population, i.e., a diadromous form, which migrates from freshwater to marine habitats, and a non-diadromous form, which occurs in freshwater environments throughout its entire life (Taylor 1999). In these polymorphic populations, the non-diadromous form generally has a smaller body size at maturity and more gill rakers or narrower gill raker spacing than those in the anadromous form, which migrate from the marine to freshwater (Foote et al. 1999; McKinnon and Rundle 2002).

However, if there are any physical barriers to their migration route, the migratory populations become landlocked, completing their entire life in the nursery beds of rivers and floodplains wetlands. After being landlocked by natural barriers such as dams created by activities of animals (beavers) and formation of sediment bars due to wind mediated sediment deposition (wind throws) using the period spanning from years to decades, some of those migratory fishes have been completely isolated by artificial barriers such as man-made dams, resulting in the prevention of gene flows.

For migratory fishes, geographic barriers temporarily isolate local populations in terms of geological time scales, while their high mobility promotes the reorganization of different populations under different selection regimes, creating spatiotemporal heterogeneity in trait distribution within and/or among populations. As a consequence, a multimodal distribution of phenotypes may be observed at a given time and space in relation to trophic morphology as well as life history traits. This may explain why polymorphic phenomena, such as trophic polymorphism or a species pair, have often been reported for freshwater fishes with a diadromous origin.

3.9.2 Rapid Evolution of Trophic Polymorphism

Introductions of non-native species, by the human beings directly or indirectly have been considered a serious conservation issue worldwide, which also can provide unexpected opportunities to study the evolutionary process of trophic polymorphism. In the original and natural population, two different feeding morphs exist with their foraging adaptations for different food components. The littoral or benthic morph has an enlarged body depth and long pectoral fins, indicating a feeding specialization towards benthic prey, while the limnetic or pelagic morph has a slender body and short pectoral fins, which give an advantage in searching for zooplankton in pelagic waters (Ehlinger 1990, 1991; Wilson 1998).

3.9.3 Genetic Mechanisms of Trophic Polymorphism: Habitat Preference

The assumptions behind the origin and maintenance of phenotypic polymorphism within a population are:

1. Genetic variation, reshuffling of gene pools through generations
2. Phenotypic plasticity, representing ontogenetic phenotypic changes in response to changes in the environment

Trophic polymorphism in fishes originates due to the direct association of genetic characteristics responsible to cause variabilities of feeding morphologies of fish by genetic effects. Alongside, the impact of environment on phenotypic polymorphism cannot be ruled out as this proposition has been substantiated by the experimental evidences which have revealed that the alterations of fish habitats tend to impart impacts by alternating their growth, and imposing morphological plastically to adjust to a new habitat.

Such phenotypic plasticity displaying trophic polymorphism in fish plays a determining role in developing intraspecific phenotypic variation and judtify its ecological significance of during ontogenetic habitat shifts. Recent advances in molecular techniques such as comparative genomics, genetic mapping, candidate gene approaches, transcriptomics etc. have stimulated studies to elucidate the genetic mechanisms of phenotypic polymorphism in fishes (Ellegren and Sheldon 2008).

3.10 Niche Construction vs Trophic Cascades

A member of a biological community embedded within an ecosystem can impart number of effects on other individuals simply by utilizing the space and energy available within the respective ecosystem. These kind of interspecies interactions in turn affects the structural components, their relationships and resilience of the ecosystem In such an interaction network, species having most intense impacts on community and ecosystem processes are termed "**keystone species**" or "**ecosystem engineers**." Defining an environment as the sum total of physical, chemical, and biological characteristics of the surroundings of an organism under consideration, phenotypes of the keystone species can shape their environments.

The environments altered by the keystone species may, in turn, act as a driver for the evolution of both itself and other members of the community. The process by which phenotypes expressed by a given species shapes the adaptive landscape of phenotypic evolution for itself or other species through alteration of biotic and abiotic attributes of their environments is termed "**niche construction**" (Odling-Smee et al. 2003).

In aquatic ecosystems, although there are a large number of examples of niche construction by fish acting as keystone predators, two key mechanisms of trophic cascade and nutrient transportation can be recognized. Trophic cascade is defined as a food web consequence in which predators have indirect effects on nonprey organisms at trophic levels lower than those of their prey, through trophic interactions within a food web (Carpenter et al. 1985).

For example, in the presence of planktivorous fish, large-bodied zooplankton is preferentially eliminated from the plankton community through fish predation (Brooks and Dodson 1965). This predation effect can alter microbial communities including microalgae, bacteria, and protozoa. Since large-bodied zooplankton such as daphnia has higher grazing rates, they depress growth of their microbial prey to a greater extent.

Despite their microscopic size, microalgae and bacteria display strong power of influencing ecosystem processes, including production and decomposition rates, because of their large biomass and high-metabolic turnover. When the abundance of planktivorous fish increases, microbial communities enhance their production and decomposition through alleviation of predation by large-bodied zooplankton, resulting in an alteration of aquatic environments.

The mechanism of nutrient transportation is more effective in a situation where predator fish move from productive to less productive habitats (Vanni 2002). For example, when a large shoal of anadromous fish migrate from the ocean to oligotrophic streams and lakes, or when benthic fish exhibit vertical feeding migration from the lake bottom to surface waters in which nutrients are prone to be depleted, a supply of nutrients is transported to the less productive habitat as their excreta or their body mass themselves. The transported nutrients are quickly consumed by microalgae and bacteria, increasing their production and decomposition rates.

This fish-driven nutrient transportation can have a substantial effect on material cycling within an ecosystem. In this way, fishes that are considered keystone predators of aquatic ecosystems have the potential to drastically alter community structure and ecosystem processes through trophic cascade and nutrient transportation.

3.11 Predator Diversity and Ecosystem Functioning

In order to highlight the contribution of biodiversity for the benefits of human beings, attempts have been made to elucidate the relationships and interactions of different biodiversity components in the process of ecodynamics in an ecosystem (Kinzig et al. 2001).

Considering that terrestrial plants provide a variety of ecosystem services (humankind benefits from a multitude of resources and processes supplied by natural ecosystems, such as supporting, provisioning, regulation, and cultural services as highlighted in the report of Millennium Ecosystem Assessment 2005), it is obvious that the conservation of plant species diversity, not only results increased primary production but also provides considerable benefits to human being.

Several theoretical models have been proposed and subsequently an increasing number of empirical studies have been conducted, for both animal and plant communities, to test the hypothesis that biodiversity enhances ecosystem functioning (Waide et al. 1999).

3.11.1 Functional Roles of Predators: A Perquisite to Understand Fish Biocenosis

Till date, very sparse number of research studies have been undertaken in order to examine and depict the mode of actions by which the predators affects the biotic components of the community and also determine the community interactions in the ecosystem processes (Straub and Snyder 2006; Schmitz 2009). However, overcoming such difficulties pertaining to the functional roles of predators on community structure and ecosystem processes, biomanipulation of the diversity of trophic morphs or a pair of species of fish predators is required. Trophic morphs are usually different only in trophic and life history traits and, otherwise, share all other ecological characteristics.

By comparing different morphs or by manipulating a combination of these morphs within a predator population, the functional roles of phenotypic diversity of a focal trait affecting the structure and functional manifestation of the concerned community can be assessed. In tune with this idea, the roles of intraspecific phenotypic variation among predator fish populations in altering community structure of prey population under natural conditions have been shown by Post et al. (2008).

3.12 Fish Trophic Interaction

The diagrammatic representation of food web can depict the overall energy flows through trophic interactions within an entire community (Lindeman 1942). Since the time of Eltonian pyramid (Elton 1927), a variety of research based ideas to have described the structural uniqueness of intricate food webs in nature. One of promising measures to characterize food web properties is **food chain length (FCL)**, representing the mode of energy transfer through trophic interactions from primary producers to a top predator, which can be measured and compared across ecosystems (Post 2002a, b).

In river ecosystems, the **FCL** can be the best explained by the size and volume of the water bodies in volume (Post et al. 2000; Okuda et al. 2012). However, aquatic ecosystem with all of its structural components undergoes variation temporally and spatially .The possible mechanism to cause temporal variation in the **FCL** may be compositional and functional changes in plankton and benthos prey communities, which can affect the number of trophic links.

In aquatic food webs, there also exists a general rule in which larger organisms eat smaller ones and becomes fewer in number, so that organisms increase their trophic levels and decrease abundance with their body mass (Cohen et al. 2003). Based on the allometric relationship between body size and biomass (body mass multiplied by the numerical abundance in each size class), size distribution of entire community can be formulated as the size-biomass spectrum, defined as the slope of body mass-biomass regression (de Eyto and Irvine 2007; Jennings and Mackinson 2003). When the community size distribution skews towards smaller-sized organisms, the size-biomass spectrum slope become steeper.

3.12.1 Eco-Evolutionary Feedbacks

The process of reciprocal interplaying in between ecology and evolution over contemporary time scales, designated as "**eco-evolutionary feedback**," tends to establish the relation and mutual exchange in between ecology and evolution. There is no doubt that intraspecific phenotypic diversity of fish predators is an important driver for altering prey community composition and thus ecosystem properties. However, ecosystem alteration, as a consequence of fish phenotypic diversification, creates new aquatic environments, i.e., niche construction, which can shape the adaptive landscape for the evolution of species of both predators and preys. Ecological interactions between a keystone species and other biotic components of community cause changes in their adaptive traits in the process of evolution by the altered environmental conditions and, such adaptive evolutionary changes in turn determine and shape the pattern of ecological interactions.

3.13 Community Ecology Based on Fishes

Interactions among species competition, predation, and symbiosis are of the functional aspects of fish community ecology. Prey–predator and competitive interactions have been recognized as an important determinant of fish community which take into consideration the species and size of predators overexploiting their prey populations and thereby alter the abundance and population structure of their preferred prey or targeted species; alter the community structure of aquatic ecosystems by removal of key species; ensure optimization of benefit–cost ratios; produce a profit all those attributes independently or combindly contribute to fitness of fish or growth of an enterprise.

Owing to the rich data sets and analyses of exploitation in fisheries, ecologists interested in predation have much to gain by being familiar with the fishery literature and by interacting with fishery scientists. Long-term data collected by fishery agencies on fishing, intensity and the abundance and distribution of fishes can be especially useful in analyses of predation.

Curiously, this interaction in fisheries ecology, while it includes fish as a side line, focuses on reptiles, decapod crustaceans, and primates. Northcote (1987) noted that predation is the dominant mechanism by which fish influence the aquatic biotic lake communities, but other than that, other "**fishy**" mechanisms also play a role, namely, excretion of nutrients, decomposition of carcasses and associated nutrient release, and migratory transport of nutrients from high- to low-productivity environments.

In such context, the fish predation has been found to impart in controlling roles in the dynamics of zooplankton, phytoplankton, periphyton, macrophytes, and zoobenthos (Northcote 1987). The fishery science is moving away from a single central paradigm that the diversity, productivity and dynamics of biotic communities to the regulatory approach on the budgeting of the inputs of nutrients and energy at the bottom of the food web.

The importance of fish predation to community dynamics was heralded in the 1950s and 1960s by Hrbacek (1958) and Brooks and Dodson (1965), and the scopes for using water quality parameters along with their management strategies to interpret the eutrophication of aquatic bodies came during 1970s and 1980s (Shapiro 1975; Shapiro and Wright 1984). The basic idea is that natural and human caused changes in the abundance of top consumers, i.e., fishes, cascade (Carpenter et al. 1985) down through the food web and regulate not only production and consumption at lower levels but also the availability of nutrients by altering the biomass available for production at the various levels. Such control is often altered with an increase in piscivorous fishes leading to a decrease in zooplanktivorous fishes, which in turn leads to an increase in herbivorous zooplankters, decrease in phytoplankters, and an increase in dissolved nutrients.

The application of these complex interactions comes both in terms of fisheries management and water quality management through the biological control by human manipulations of the food web which leads to an invoke on the abundance of desired fishes and water clarity. The influence of fish predation through the complex interactions above is apparent not only in the abundance and density-dependent growth responses of its prey but also in the biomass and productivity of organisms several trophic levels below.

The fish can alter both ecosystem processes (primary productivity; Northcote 1987; Carpenter and Kitchell 1988) and a set of water characteristics pertaining to quality and clarity of water such as mixing depth, surface and midwater temperatures, and heat content (Mazumder et al. 1989) which all together affect the biomass and size structure of phytoplankton. Thus, effects of predation on community dynamics expand into effects on ecosystem processes including the external abiotic influences (climatic, edaphic or nutrient-related, and morphometric factors) on aquatic productivity of the entire riverine ecosystem (Rawson 1939, 1952; Cole 1983).

3.14 Role of Abiotic Factors on Fish Production

The single abiotic factor that best estimated fish production, measured as yield per unit of river area, was mean depth (Rawson 1952; Ryder 1965, Matuszek 1978). The second most important factor was the, total dissolved solids (**TDS**), an edaphic factor. Fish production is thought to be related to mean depth because it correlates inversely with the size of the littoral zone within the euphotic zone, the sinuosity of the shoreline, water temperature, mixing depth, and dilution of nutrient inputs (Ryder et al. 1974).

Both of these parameters have their effects on the production of benthos, both plants and animals, length of breeding and growing periods, and rates of biological productivity. Ryder (1965) posited that the ratio between total dissolved solids and mean depth summarized two of the principal types of factors and could be turned into a morphoedaphic index that could be used to understand and also to predict the yields of fish in different water bodies including freshwater habitats, such as reservoirs and rivers (Ryder et al. 1974) with minimum data requirements. Schlesinger and Regier (1982) added the influence of latitudinal climatic zones to the prediction of fish yield from the morphoedaphic index. Further, analyses demonstrated close relations between fish yields per unit area and other biological factors of the water bodies such as phytoplankton biomass or production and benthos biomass (Oglesby 1982). The basic idea is that natural and human caused changes in the abundance of top consumers, i.e., fishes, cascade down through the food web and regulate not only production and consumption at lower levels but also the availability of nutrients by altering the biomass available for production at the various levels (Carpenter et al. 1985).

Often the control is experienced in an alternating pattern, with an increase in piscivorous fishes leading to a decrease in zooplanktivorous fishes, which in turn leads to an increase in herbivorous zooplankta, which in turn leads to a decrease in phytoplankters, and also which in turn leads to an increase in dissolved nutrients.

The application of these complex interactions comes both in terms of fisheries management and water quality management through the biological control that human manipulations of the food web can invoke on the abundance of desired fishes and water clarity. The influence of fish predation through the complex interactions above is apparent not only in the abundance and density-dependent growth responses of its prey but also in the biomass and productivity of organisms several trophic levels below.

The knowledge base developed out of such complex interactions can be used for fisheries management and maintenance of water quality parameters. Human manipulations of the food web can invoke and boost up the abundance of desired fishes and water clarity. The influence of fish predation through the such complex interactions is apparent not only in the abundance and density-dependent growth responses of its prey but also in the biomass and productivity of organisms several trophic levels below, because phytoplankton biomass and size structure can be affected. The fish by imposing foraging pressures on the phytoplankton affect their sizes and biomass can also alter both a host of ecosystem processes such as primary productivity (Northcote 1987; Carpenter and Kitchell 1988) and a set of characteristics influenced by water clarity such as mixing depth, surface and midwater temperatures, and heat content (Mazumder et al. 1989). Thus, effects of predation on community dynamics expand into effects on ecosystem processes and effects on the riverine ecosystem as a whole.

3.15 Riverine Floodplain Connectivity and Fish Diversity

River–floodplains being one of the productive aquatic ecosystems have been under the threats of eco-degradation all over the world, mostly because of anthropogenic activities. Floodplains are used by fishes in multifarious ways such as for foraging, spawning, and nursery habitat. In a large river–floodplain system, the ecological response of fish to flow regime can be assessed by monitoring and recording of research information pertaining to two major relationships:

1. Discharge and the extent of inundated floodplain area highlighting floodplain connectivity of floodplains in the spatial and temporal scales
2. Volume of water and intensity of current during flood volume along with total quantity of fisheries yield

Differential rate of discharge coupled with periodicity of inundation pressure have resulted a nonlinear relationship between discharge and inundation. Moreover, the extent and duration of inundation are mostly decided by the average volume of flood water instead of water volume during the period of peak discharge. The quantity of the production of fish from the river–floodplains exhibit significant annual variations and differ considerably from the quantum of fish catches of the main river, pointing out the causes (increased access to more somatic growth, higher availability of fish foods, maximum utilization of sunlight, etc.) resulted from the stimulated and triggering effects flooding within the floodplain, but not in the river.

All the species of fish deriving benefits from flooding in the floodplains belong to different feeding guilds, highlighting the scopes of having more benefits getting for all trophic levels during the period of flooding. However, river floodplains representing a transitory ecozone between terrestrial and river ecosystems not exhibit higher productivity but suffer considerably from multifarious human activities across the world (Junk et al. 1989). Regulation of river flow regimes has resulted in homogenizing of flooding dynamics which in turn result eco-degradation of habitats and also cause the reduction of habitat diversity in several floodplains of the world (Poff et al. 1997; Bowen et al. 2003; Poff et al. 2007). Numerous fish species use floodplains for spawning, as nursery and as foraging habitat. Recruitment of fish, their somatic growth, biomass, and total catch have revealed a similar trend of increase with the increase of flood magnitude, size of inundated area and connectivity of floodplains water with the main river (Amoros and Roux 1988; Gutreuter et al. 1999; Grift 2001; Sommer et al. 2007; Amoros and Bornette 2002; Miranda 2005; Schram and Eggleton 2006; Probst et al. 2009; Frazier and Page 2009; Van de Wolfshaar et al. 2010).

In spite of having lot of baseline research information of the diversity and biological attributes of fishes, an ecological understanding on higher species diversity coupled with maximum fish production in river–floodplain systems indicate strong positive correlation with fishery production due to habitat availability in the heterogenous habitats promote higher fishery production. In such context, strategic and systematic conservation planning and management steps taking into consideration of river flow regimes and also other human intervening factors are primarily impelled by the demands for hydropower, irrigation, navigation, and safety can bring forth realistic outcomes pertaining to the eco-biological management of flood plains (Vasilevskii et al. 2001; Poff et al. 2007). The positive relationships have also been recorded in between fish catch and flood volume as different species of fish displayed diverse flow preferences, for flow patterns, spawning and feeding guilds.

Research studies on the roles of embanked floodplains as foraging area have suggested that the rivers serve to provide refuge for floodplain fish (Aarts et al. 2004).

Despite the facts of wide recognition of the contribution of the flood pulse concept (Junk et al. 1989; Poff et al. 1997), establishment of relationships among river discharge from the rivers, extent and patterns of floodplain inundation, and mode of connectivity of floodplains with rivers has not acquired that much attention from the river scientists with regard to the systematic eco-management of floodplain ecosystem in general and conservation of bioresources in particular (Vaughan et al. 2009).

In such context, it can be hypothesized that increased habitat heterogeneity coupled with enhancement of availability foraging habitats of fish in the floodplain due to the flooding and inundation, extended connectivity among the adjoining ecosystems, higher supply of both autochthonous and allochthonous nutrients, growth and propagation of live foods for fish (plankta) promote somatic growth of fish along with the enhancement of fish biomass, which is reflected in higher fish catch (De Graaf 2003a; Schram and Eggleton 2006).

Different feeding guilds of fishes have been found to earn benefits in respect of having more habitat heterogeneities and nutrients availabilities from flooding which strengthen the proposition and concept that different biotic components representing their respective trophic levels in the floodplains enjoy such advantages from flooding. River–floodplains being highly productive ecosystems along the riverine flows are prone to suffer from human-mediated threats worldwide (Junk et al. 1989). Nonjudicious, unplanned, and unscientific regulations of river flow regimes have resulted in homogenizing of flooding dynamics which in turn result habitat degradation and also in the shrinkage and restriction of habitat diversity in many floodplains (Poff et al. 1997; Bowen et al. 2003; Poff et al. 2007).

All those assessments have led to develop the hypothesis that developing of maximum fish biomass coupled with increased somatic growth of individual fish as reflected by higher fish catch is directly related to an increase in available foraging habitat, conducive ecological condition, diverse flow preferences, spawning, and feeding guilds. With preferred availability of foods in the floodplain. This hypothesis is also based on the assumption of positive relationships among flood volume, inundated area, and water body connectivity (De Graaf 2003a; Schram and Eggleton 2006).

3.16 Diversity of Fishes in Tropical Asian Rivers: Ecological Reality and Constrains

Rivers in the tropical Asia rivers support the lives of a galaxy of fauna in the form of planktons, nekton, and fish), benthos, periphyton, besides an array of other higher chordates such as amphibians, reptiles, birds, and mammals who seek the river environment (main river flows, floodplains, associated wetlands, riparian forests, grasslands, scrublands, etc.) for their shelter, water, food, and often for reproduction.

River ecology, mostly centering on larger fauna such as fish and zoobenthos is mostly determined by two major meteorological parameters, i.e., temperature (drive hydrological cycle by evapotranspiration) and rainfall (control flow seasonality). Documenting the diversity of fishes also requires research information on habitat preference, life history, feeding strategy, trophic interactions, migration patterns, seasonality of occurrences, and the availability with the mode of utilization of allochthonous and autochthonous nutrients.

Migration of fishes is also with very close relationships with breeding which decide the settlement of fishes in the suitable habitats in the preferred season. Riverine biodiversity has been threatened by several human-mediated activities such as construction of dams, flow regulation, destruction of habitats by deforestation of drainage basins, deterioration of soil and water quality by both point, and nonpoint pollution, as well as overharvesting of bioresources. Proper systematic and strategic conservation efforts for the biodiversity of tropical rivers are handicapped by the paucity of ecological research information alongside the public awareness with strong socio-political commitment towards environmental protection can become determinants for the wellbeing of the future of riverine biodiversity.

3.16.1 Fishes: Life Histories, Trophic Relations, and Production

Information on the ecology of fishes in tropical Asian rivers is considerably more comprehensive than that for invertebrates but is nonetheless surprisingly meager. Standing stocks in small rivers seem to be somewhat lower than those reported for north temperate streams with comparable water chemistry, but this generalization is based on few studies.

Detritivorous species are not only affected by biogeochemical cycles but by virtue of their higher abundance can influence biogeochemical processes, especially carbon and nutrient cycling by controlling organic matter content in the sediments because of their ability to modify the quantity and nutritional quality of sediments in a floodplain river (Winemiller et al. 2006). The detritivores are considered as ecosystem engineers as they play a crucial role in substantially affecting the overall fluvial bioenergetics budget (Taylor et al. 2006; Flecker 1996). Proper understanding of the differential patterns of responses of fishes to riverine flows also yield insight for integrating different phases in the life cycles of fish with the prevailing biogeochemical cycles and fluvial geomorphology, because both of these processes are reconciled at least partially, by fluid dynamics. Besides, the consequences of shifting from the insect dominated biotic assemblages to fish-dominated systems in the continuum of river gradients, some important implications in shaping the community structure can be observed.

First, fishes as macroconsumers process large volumes of organic materials in the feeding functioning relative of their body size. This is very much prevalent in the tropical regions where fishes attain large sizes along with high abundance and increased metabolic rates in comparison to their temperate counterparts. Moreover, most of the fishes are endowed with excellent visual strength in addition to their power of mobility and both of which have made them successful hunter for chasing preys and wide-ranging foraging activities. Such improved adaptability of fishes as an efficient foragers capable of fast harvesting of foods and utilization of resource-rich patches over spatial scales outcompete the insects' community of rivers and streams. These facts can also substantiate the claim that the rate at which organic matter is cycled in the riverine ecosystem is more in the tropical rivers than the temperate ones.

Second, fish being macroconsumers attain large size, and harvest a new array of resources to make them available and suitable for the consumption and thereby many of the resource bases not readily digestible to insects may become important food resources to tropical fishes (Flecker 1996).

Moreover, owing to the variation in the scales of selectivity between micro- and macroconsumers, deposit-feeding insects may select particles individually in contrast to detritivorous fishes, which scour mouthfuls of sediment without prior selection and subsequent processing of the harvest as foods and the power mobility of fishes enable them to shift their positions among different resource patches of varying quality. However, some stream fishes practice particle selectivity which takes place generally in the buccal cavity following the dislodging the sediments in the habitats and thereafter collection within the mouth with the aids of power full jaw suspension (Bowen 1987).

The yields of fish from the rivers and associated floodplains are found to be regulated substantially by the inter-annual variation of the intensity of the monsoon, which accelerate the flood pulses (the advancement and retraction of water over the floodplain in a predictable manner). Many fishes show highly seasonal feeding activity, experiencing alternate periods of resource scarcity and resource glut during the dry and wet seasons, respectively. A wide range of foods in the form of allochthonous dietary items, such as terrestrial insects and fruits, is utilized by the fish, and their use seems much greater than those lotic fishes of temperate rivers. Many Asian river fishes migrate within river systems which involve a significant upstream or lateral component, in addition to return or downstream movements. They are frequently, but not invariably, associated with breeding and are timed to exploit allochthonous foods from inundated floodplains or riparian forests. Thus these are not only breeding migrations but also represent migrations to superior living space.

Most species that depend upon the floodplain for food and breeding sites show marked inter-annual variation in production. The fishes differ with respect to breeding habits also: many benthic species are multibrooded and practice parental care (mouth brooding, bubble-nest building). In addition, these fishes can tolerate deoxygenation of stagnant floodplain waters because they have accessory breathing organs, whereas most pelagic whitefishes spawn only once per season and scatter their eggs. Roberts (1998), states "...the entire field of fish reproductive biology, including timing and stimulus of reproductive migrations, time, place and requirements for spawning, physiological adaptations of eggs and larvae, and comparative reproductive biology of carps, catfishes, and other groups under natural conditions, is largely untouched..."

3.17 Fishery Potential in the Freshwater Riverine Networks of Different Districts of South West Bengal: Diversity

3.17.1 Three Major Districts of South West Bengal, India with Fishery Potential

3.17.1.1 Midnapore (West and East) Districts, West Bengal, India

The erstwhile undivided Midnapore district of West Bengal, India, has been gradually slopping from the Chota Nagpur Plateau to Kanthi littoral plain of Bay of Bengal. Southeastern part of the district receives high rainfall, which gradually decreases towards the northwest. Western part of the district is covered with forest (almost **30%**), where agriculture is the main occupation. The wetlands are very rich with floral and faunal diversity. Owing to the higher probability of mixing of tidal water, the coastal areas in the eastern part of the district have a favorable ecological condition for the development of fisheries. The wetlands in this region are therefore, serving as a natural storehouse of genetic resources stored in an array of floral and faunal biodiversity components. This has been reflected from the livelihoods of the local peoples who have adopted has pisciculture and other fishery-related activities as their main occupation in this region because a significant amount of fishery resources are seen to have been harvested by the local peoples from different aquatic bodies such as rivers, streams, rivulets, wetlands, irrigation canals, floodplains, and paddy fields.

3.17.1.1.1 Hooghly District, West Bengal, India

In Hooghly district, the fisherman communities are not fully dependent on fishery activities. This has been fully supported by the statistical estimation, which shows that around 2% of the total population is involved in the profession of artificial breeding of fish and nurturing of young fish fingerlings and fry.

3.17.1.2 Bankura District, West Bengal, India

The large proportion of fishes of this district is collected mostly from tanks, irrigation canals, and rivers. In the dry season, large prawns and carps are collected in the shallows of the rivers.

3.17.2 Diversity of Riverine Fishes in South West Bengal, India: Diversity and Dynamics of Ichthyofauna

An eco-biological assessment of the environmental quality of aquatic ecosystems should incorporate different attributes pertaining to biological diversity, dynamics, behavior, and eco–geo–biological processes at different tiers of ecosystem functioning. The latest approach to assess the integrity of environments are multimetric, aiming at combining attributes that represent the broad existing ecological diversity at different levels of biological organization (Casatti et al. 2009). Although, the South West Bengal is endowed with a network of several freshwater rivers and their tributaries, the surface water alongside ground and subsurface water are very scarce in this region of West Bengal, India, because of several reasons ranging from geomorphological to limnological one, and support least faunal biodiversity.

As such no publication is available with regard to biodiversity of higher chordates (fishes, amphibians, reptiles, aves, and mammals) and benthic fauna (mollusks, insects, oligochaetes, crustaceans, etc), excepting a few publications on zooplankton (Pradhan and Chakraborty 2008; Mishra et al. 2003). In such context, the study of the diversity of freshwater fish species along with other biota holds great promise towards ecological integrity of the riverine environment of water scarcity zones of South West Bengal, India. Scientific documentation of ichthyofaunal resources in the two major freshwater rivers of West Bengal, India, viz., Subarnarekha and Kansai and their river basins, have been made along with analysis of the integrity of riverine environments using a multimetric approach. The studies of the ecological guild of fish have assumed great importance because the research information of the zonations of fish in tune with their foraging and reproductive needs can be used to undertake eco-management strategies with an understanding of the ecological integrity of large rivers and the mode ecological dynamics (Aarts and Nienhuis 2003).

Shifting in the structure of functional ecological groups as a result of environmental changes on sustaining the different natural and man-made ecological threats can be explained by several theories, hypothesis, and scientific interpretations based on baseline information of river ecology, geomorphology, and biodiversity. These scientific knowledge bases in turn help set proper guidelines for ecological restoration of river systems by unearthing the underlying scientific principles pertaining to ecological processes and dynamics of different habitats (Vandewalle et al. 2010).

Alongside incorporating fish guild approach for ascertaining fish assemblage patterns, the evaluation of biological integrity and variations in the trophic organizations/interactions can be considered to be the indicators of the changes in the quality and complexity of a habitat (Karr 1981). Application of **Niche Filtering Hypothesis** enables to interpret the regulatory roles out of interactions both abiotic and biotic factors determining the local scale species assemblages which act simultaneously in conjunction of other with physical parameters and changing patterns of the environmental flows such as volume and density, turbidity, current, etc. of water;

erosion and sediment disposition, depth of soil, sand lifting, and other anthropogenic activities which will act upon as filter causing severe constrains on the fish population to survive (Zobel 1997; Mouillot 2006).

3.18 Fish Diversity and Indices

A total of **267** species of freshwater fishes including **186** primary freshwater species, belonging to **12** orders, **40** families, and **123** genera from the freshwater bodies and their associated brackish water zones of West Bengal have been recorded, of which the top three orders are represented by the Cypriniformes (**117** species, **46** genera, and **4** families), Siluriformes (**79** species, **36** genera and **12** families), and Perciformes (**39** species, **17** genera, and **10** families) (Mogalekar et al. 2017). Considering the necessity of developing baseline information in respect of Ichthyofaunal diversity of South West Bengal, India as a prerequisite for adopting proper conservation strategies, six rivers, **viz.**, Subarnarekha, Kansai, Keleghai, Shilabati, Dwarakeswar, and Rupnarayan, originated either from Bihar plateau or from upland of Purulia flowing through the Midnapore district and ultimately ending to Bay of Bengal via Hooghly estuary, and constituting the main freshwater habitats of fishes of South West Benga1 have been surveyed to record the fish and fishery resources following the standard literature (Day 1875; Hora and Mukherji 1953; Sen 1985; Jayaram 1981; Talwar 1991; Menon 1992). This paper records 103 species of fishes belonging to 76 Genera under **33** families and **11** order of the class Pisces from different freshwater habitats of South West Bengal, India. Out of total Ichthyofauna, the maximum number of species (**29**) belongs to the order Cypriniformes followed by Perciformes (**26**), Siluriformes (**25**), Clupeiformes (**7**), Chenniformes (**4**), Atheriniformes (**3**), Mastacembaliformes (**3**), Osteoglossiformes (**2**), Pleuronectiformes (**2**), Anguilliformes (**1**), and Synbranchiformes (**1**). **27** species of fishes have been found to intrude in the adjoining brackish water zones. Out of **103** species, **101** species have been reported for the first time from this region. A similar study has also revealed the occurrences of a total of **89** species belonging to **62** genera and **17** families from the Subarnarekha river–estuary of which only **39** species under **26** genera and **13** families were found in the freshwater zones of this river, whereas the Kansai river has supported a diversity of fish fauna of 33 species under **22** genera and **11** families (Tables 3.1, 3.2 and 3.3; Figs. 3.2 and 3.3). Out of the total of **103** fish species collected from all six rivers of the south West Bengal, India, **101** species have been reported for the first time and the other two species, **viz.**, *Chela cachius* (Hamilton Buchanan); and *Esomus danricus* (Hamilton Buchanan) were reported earlier from Damodar and Rupnarayan rivers, respectively. Out of ·**103** species documented from different freshwater bodies (lentic and lotic) **29** species are found to inhabit in both fresh and saline water bodies. The occurrence of these fishes (**29**)· in both freshwater and saline water is supposed to be due to their wide range of salinity tolerance. A comparison of the present study with those of mentioned above clearly showed that the fishery potential of freshwater bodies of South West Bengal, India is still very commendable. As many stresses, **viz**., pollution due to rapid industrialization and urbanization, construction of barrages and dams, nonjudicious lifting of water from river bed for the purpose of irrigation and municipality, deforestation followed by soil erosion, over exploitation of ichthyofauna during breeding seasons, use of ichthyotoxic chemicals and plant extracts for fish harvesting, use of lilon thread net having smaller mess sizes, etc. causing degradation of fish environment are increasing; an immediate proper conservative strategy should be made for the protection of this valuable bioresources (Mishra et al. 2003).

3.19 Environmental Assessment of Fish Habitat

3.19.1 Physicochemical and Microbial Parameters

The world is changing rapidly. These changes involve transformation of the landscape and waterscape with accompanying changes in the populations of many species of plants, animals, and microorganisms. Populations of some species have been drastically reduced and disappeared due to overexploitation and pollution (Dehadrai et al. 1994). Wetlands – including rivers, floodplain wetlands, streams, lakes, marshes, estuaries, and lagoons – are among the most fascinating and complex ecosystems on earth, and they act as integrating nearly all aspects of human culture by acting as the center of different ecological processes within the landscape.

The roles of all those water bodies in offering natural resources, such as foods (fish, mollusks, hydrophytes, etc.) and clean water, are well-known, as are their roles in contributing towards transportation, energy, diffusion on wastes, and recreation. They exhibit enormous diversity in size and shape according to their physical and chemical composition. Characteristics of flora and fauna largely depend on physicochemical parameters as well as biological features of water bodies. In the present era, keeping pace with an ever increasing demands being made on aquatic resource by an exponentially increasing human population, basic ecological understanding of the structure and ecodynamics of lotic water ecosystem of running waters is essential has become prerequisite to for formulating sound and sustainable water resource management and also to device proper and policy decisions.

The physical, biological, and ecological characteristics of rivers and streams act as integrators of wide range of ecological conditions as they reflect the ecological conditions of the surrounding landscapes (Naiman 1997; Naiman et al. 1992). Owing to different natural or anthropogenic (human-induced) factors, the water bodies gradually becoming nonproductive (Jhingran 1983; Weyand et al. 2005). All of these alterations, singly and in combination, directly influence the habitat patterns, the trophic structure, the physical, chemical, and biological processes (such as sediment transport, nutrient cycling, and primary production), and the demography of the biological communities.

Environmental flows of the large river systems have become altered by the fragmentation of the river channels by the development of dams, hydroelectric power stations, and similar built structures for water regulation, inter-basin diversion, and irrigation (Dynesius and Nilsson 1994). Many non-point pollution are land specific, especially agriculture, mining, and overall urban uses. Among all non-point sources, the contribution of agriculture is more important in the area under study that affects the rivers and adjoining water quality most. When runoff flows over soils and rock, it dissolves many substances and become highly mineralized. Water flowing across vegetated areas also dissolves many organic compounds. Both organic and inorganic matters are suspended in runoff.

Further several reactions occur between dissolved substances as well as in between dissolved and suspended substances (Haslam 1974; Ravindra et al. 2003; Liu et al. 2013; Cao and Ikeda 2005; Vondracek et al. 2005; Fafioye et al. 2005; Domenech et al. 2006; Haraldsen and Stålnacke 2006; Sargaonkar 2006). Chemical fertilizers, pesticides and insecticides are widely used in India in agriculture for pest and vector control.

The use of organochlorine pesticides has not yet been banned, although it is used indiscriminately. The organophosphorus, carbonate pesticides are being applied profusely in the agricultural sectors in India. Quasim and Sen Gupta (1982) reported that the average quantity of fertilizers used in India **1530.5 kg ha-1 year-1** which would give an annual total of **5 × 106** tonnes for the entire agricultural land in the country. About **77,000** tonnes of pesticides were used in the year **1980** for different purpose and the figure for synthetic detergents was **125,000** tones. There has been a progressive increase in the use of both pesticides and insecticides every year.

During the last **10** years, heavy metals have become a common pollutant in the freshwater (Whitten and Say 1975). Excess inputs are of man-made origin coming from industrial and mining effluents, pesticides, the burning of fuels, and car exhausts. According to Glasby and Roonwal (1995), a major source of metal pollution in India is fly ash from power stations.

According to recently compiled statistics, approximately **280 × 106 tonnes** of fly ash is being produced in the world every year by the combustion of coal (Hockely and Sloot 1991). The main source of organic pollution are municipal sewage, fertilizers, farm wastes from agricultural areas, lavatories, kitchens, laboratories, and from domestic and industrial units. According to Simmons (1974), domestic sewage being an organic pollutant contains wastewater (**99.9%**) and total solid waste (**0.02–0.04%**) of which proteins and carbohydrates each comprise of **40–50%** and fats **5–10%.**

In recent years, rapid population growth, increasing living standard, wide spheres of human activities, and industrialization have resulted in greater demand of good quality water, while on other hand, pollution of water has been also steadily increasing (Murugesan and Sukumaran 1999) as a result of which, freshwater ecosystem has become globally threatened. **I.U.C.N**.2007., The World Conservation Union has already estimated that more than 1 billion people in developing countries hardly have access to clean water. A family having four members four requires about **1600 liters** of water per day (of which only about **3%** is used for cooking and drinking) alongside major consumption for agriculture and industries (**70–80%).**

In contrast, the consumption rate in water-stressed areas in developing countries is only **50 l/d to 75 l/d** per person or **300 l/d per** family (Powledge 1984; Gleick's (1998)), More than **70–90%** of the freshwater resources are being withdrawn only for irrigation, which alter natural hydrological regimes. Not only is agricultural consumption excessive but so is household consumption, with a typical family of four requiring about **1300 l/d** (of which only about **3%** is used for cooking and drinking). In contrast, the corresponding consumption rate in developing countries is only **75 l/d per person or 300 l/d per family** (Powledge 1984), uncomfortably close to Gleick's (1998), estimate of a minimum human water requirement of **50 l/person/d (200 L/family/d).** Environmental pollution has imparted an incompatible effect on aquatic environment for fishes to thrive. Large-scale awareness has been generated all over the world for undertaking research on this problem because of its harmful effects on different biological components of environment which ultimately hamper socioeconomic benefits of human society (Kumar 1998; Saravanan et al. 2003; Liu et al. 2004; Cao and Ikeda 2005; Vondracek et al. 2005; Gupta and Sharma 2005; Haraldsen and Stålnacke 2006; Sargaonkar 2006).

Destruction of fish habitats by alteration of river systems, increased water abstraction, overfishing of important fishes, pollution of waters, deforestation followed by soil erosion, land development, and domestication of species have been going on indiscriminately during last four decades (Holden 1965; Keswill 1967; Saunders 1969; Anon 1984; Konar 1988; Menon 1988; Ghosh et al. 1988; Das and Pandey 1998; Cheng et al. 2003; Banerjee 2003; Liu et al. 2004; Sanchez-Choliz and Duarte 2005; Sargaonkar 2006). These man-induced alterations have, naturally, been showing qualitative and quantitative changes in population structures as revealed by the decline of fisheries in different ecosystems (Das 1988; Mahanta et al. 1998). Profuse consumption of water coupled with ongoing environmental threats because of pollution, over harvesting of commercially valuable species, and the introduction of exotic species have seriously degraded many types of riverine systems, and populations of many species have become highly fragmented and modified (Degerman 2001).

Different stream organisms require several types of habitats to support different life history stages, and thereby selective habitat destruction has reduced the viability of populations. This will bring forth not only economic loss but also will permanently cause ecological degradation (Sweeney et al. 2004). Therefore, systemic and strategic management strategy for the conservation of those freshwater biotic resources, especially threatened fishes has to be devised.

Physicochemical and microbiological parameters in a particular water body provide an idea about the aquatic environment (Keswill 1967; Saunders 1969; Menon 1988; Das and Pandey 1998; Cheng et al. 2003; Banerjee 2003; Tiwary et al. 2005; Sanchez-Choliz and Duarte 2005; Sargaonkar 2006; Chandra et al. 2006; Anand et al. 2014).

Baseline information on different physicochemical parameters, and their seasonal dynamics can be utilized for having proper knowledge about the impact of such parameters on floral and faunal components of any aquatic organisms. In the present investigation, selected parameters of water, viz., temperature, pH, alkalinity, dissolved oxygen, conductivity, total coliform, fecal coliform bacteria, etc., were estimated round the year to assess the environmental health of different water bodies harboring different bioresources especially fishes (Pradhan et al. 2003, 2006, 2008; Mishra et al. 2003; Giri and Chakraborty 2002).

3.19.2 Biological Parameters

The chemical data throws light on the concentration of pollutants, but the degree of ecosystem imbalance is measured by biological information. Biological parameters for assessing environmental perturbation are termed as biomonitoring. The aquatic pollution disturbs the wholesomeness of aquatic ecosystem (Kumar 1995; Ravindra et al. 2003; Gopal and Agarwal 2003; Saravanan et al. 2003; Tiwary et al. 2005). The chemical water quality could depict only marginal variation over the years while a gradual disappearance of certain sensitive biological lives indicating the intensity of such eco-degradation.

Recently the use of biological monitoring systems as a tool has been realized in addition to monitoring of physicochemical parameters for the prediction and detection of ecological effects and to protect natural water bodies from consequences of pollution (Pradhan et al. 2003; Akin-Oriola et al. 2006; Sunkad and Patil 2004; Gupta and Sharma 2005).

A recent study has attempted to document biological components like zooplankton, macrophytes, and macroinvertebrates to assess the biodiversity, and the role of it in maintaining water quality of South West Bengal (Annon 2002).

3.20 Diversity of Freshwater Ichthyofauna

3.20.1 Diversity of Fish in India

An array of inland water bodies in the form of streams, rivers, streams, canals, reservoirs, lakes, ponds, and swamps are present in different bio-geographic regions of India. India is also gifted with vast and varied fish germplasm resources distributed widely in its varied aquatic ecosystems. About **2500** finfish species have been recorded from different ecosystems of India while more than **20,061** species reported worldwide (Jayram 1999).

These fishes have acquired varied forms of morphological features and preference for habitats, because of their adaptation to markedly varying biotypes, ranging from mountain streams having very cold water to the deepest part of the seas. Meticulous studies on morphological excellences of fishes are required for determining the taxonomic status as well as quantification of fishery productivity. These fishes are characterized by a variety of morphological and anatomical features which are used for their adaptation to diversity of habitats, and markedly varying biotypes, ecologically ranging from cold torrential mountain streams to the tropical warm water pelagic and benthic environments. In order to record and document freshwater fish communities, adequate morphological descriptions are required for taxonomical and ecological purposes (Kottelat and Whitten 1996a, b).

3.20.2 IUCN's Guidelines on Fish Diversity

The International Union for Conservation of Nature and Natural Resources (IUCN), the major world agency for conservation of animals and plants, has published some lists of species of fishes, amphibians, reptiles, birds, and mammals to be globally endangered, threatened or rare in the Red Data Book (**I.U.C.N**. First Draft 1978). But this list does not contain the endangered or threatened species of fishes of India.

Even in the Red Data Book, the details of columns on the total population, trend, habitat, etc. for several species have remained blank indicating lack of information on them. Inventory of ichthyofauna and establishment of sanctuaries of ecological refuges are essential not only for the protection of our endangered and threatened species of fishes, but it is also needed for the preservation of the genetic diversity of the different species of our freshwater fishes.

The importance of conservation of fish germplasm resources helps aquaculturists and fish breeders to make use of the new genetic variety in their attempts at genetic improvement of stock. The necessity of establishing germplasm reserves has become ever more urgent at the present moment as the pace of destruction of species in inland waters increases (Menon 1988; Datta 1988; Degerman et al. 2001).

Certain genetic varieties of fishes, which at present have no obvious economic value may be needed in the future to fulfill ever-growing requirements for developing improved and disease-resistant cultivable varieties (Menon 1988; Degerman et al. 2001; Cetra and Petrete 2006). In view of the paucity of information on ichthyofaunal diversity, it is important to document baseline information on this subject locally, regionally, country, and continent-wise to have proper knowledge on their production potential as well as their propagation possibility. In the present context, an attempt has been made to prepare the systematic account of fish species encountered during the survey of selected area under study.

3.21 Ecological Guilds of the Fish Fauna

The concept of ecological guild (Grinnell 1917; Root 1967) has become very popular nowadays to the aquatic ecologist in developing understanding and also analyzing the community structure of fish in the river ecosystem, especially based on foraging guilds (Wiens 1989; Paszkowski and William 2006). Considering ecological guilds as natural "**ecological units**" within the biotic community (Simberloff and Dayan 1991) and play a significant roles in depicting the community interactions as the "**building blocks**" of that community (Hawkins and Mohon 1989). The ecological guild was defined by Root (1967) as being "**a group of species which display similar habitat preference in order to that exploit the similar resource base in almost similar way**" and categorized that "**this term groups together species, without regard to taxonomic positions, that overlap significantly in their niche requirements**" (Jaksić and Medel 1990).

Fish can be grouped into different ecological guilds as per their eco-biological requirements (foraging habitats and spawning ground). The ecological classification of fishes is based mainly on their flow preference such as rheophilic (spending entire life in lotic waters); eurytopic (different stages in the life history occur either in lotic or in lentic waters) and limnophilic (all stages of life cycle are confined to lentic waters) groups.

A recent study of two rivers (Subarnarekha River and Kansai River) of South West Bengal, India, have shown that rheophilic fish species formed the most dominant group in Subarnarekha River while the flow patterns of Kansai River mainly supported the diversity of limnophilic and eurytopic fish groups because of almost negligible flow of water**.** The fish species were found to use five spawning habitats in Subarnarekha River (rheophilic, lithophilic, psammophilic, phytophilic, and polyphilic), whereas the river Kansai had shown the occurrence of three spawning grounds (limnophilic, phytophilic, and polyphilic)

3.21.1 Essence of Ecological Guilds: Niche Partitioning

Guild structure along with niche characteristics indicate the quantitative niche partitioning of a community. Analyzing of the niche structures help developing the understanding of the roles of resource partitioning in determining the coexistence or exclusion of different fish species in relevant guilds at different riverine habitats. Research information of the trophic guild structure and niche organization of riverine fish also can throw light with regard to the occurrence of different categories of fish based on their abundances as rare, abundant, etc.

The composition of guilds at different ecozones of the rivers differ among themselves and display positive correlation both with habitat features and the mechanism of exploitation of resources, either for breeding or foraging (Holmes and Robinson 1988). Simberloff and Dayan (1991) emphasized the significance of the guild structure and niche characteristics in indicating the trend and level of niche partitioning of a community. Groups of animal species having similar ecological roles are included in the same guild but simultaneously enjoy different ecological niche (Root 1967).

In trophic terms, in the absence of competitors, a particular species develop least specialization in comparison to those species which takes the challenge of competition (Jorgensen et al. 2007). Diversity of fishes is more in those water bodies which possess prefer those greater habitat heterogeneity and thereby provide the scopes for having more food resources in the form of hydrophytes, both as floating and submerged vegetation, variety of benthic fauna like aquatic insects, mollusks, smaller fish and larvae of amphibians. Availability of those heterogeneous habitats prompted more fish to aggregate and develop unique fish assemblages with varied strong morphology-mediated foraging behavior and helped structuring the fish community at the study sites.

It was pointed out by Simberloff and Dayan (1991) that classifying fishes based on the location of the feeding site, type of their preferred food, power and rate of consumption, and manifestation of foraging behaviors would be more indicative of local foraging resources. Based on such baseline information, the indicators can be used as a tool for monitoring the ecological integrity of aquatic ecosystem by being a part of policies and regulations (Carignan and Marc-Andre 2002). Several authors have put forward the views that competitive interactions are more likely to occur among species of the guilds than those between other species (Perez-Crespo et al. 2013; Elafri et al. 2017). Birand et al. (2012) commented that the species with narrower niche widths tend to be more affected by habitat fluctuation. Diverse feeding resources may allow for more species with varied foraging mechanisms to utilize the resources. It is more important for the establishment of a trophic guild than foraging habitats.

In the tropical megadiversity countries, freshwater fishes exhibit spectacular biodiversity in comparison to temperate regions, The temperate rivers are generally dominated by insectivorous fishes, whereas detrital and algal feeding fishes are widespread and predominant among tropical ichthyofauna. Several experimental studies have established the functional roles of several fish trophic guilds which occur in higher densities in determining the patch colonization patterns by invertebrates.

Insectivorous characid fishes mainly abundant in temperate countries tend to impart least impact on influencing overall abundance of aquatic invertebrates. Although by the foraging activities of all those fishes resulted significant reductions in the abundances of some selected aquatic taxa (the mayflies *Baetis* sp. 2 and *Leptohyphes* sp., and the caddis flies, namely, Stnicridea and Alisotrichia). The grazers and detritivores have been found to substantially reduce the amount of sediments and associated detritus which are accumulated on stream bottom substrata. Experimental studies have also elucidated that grazing and detritivorous fishes influence insect abundance. Sediment processing activities by several epibenthic fishes have been noticed to enhance the patch colonization of several benthic invertebrates.

3.21.2 Fish as a Predator: Determining Effect on Biotic Community in River

Fishes influence invertebrate populations in freshwater systems via both direct and indirect pathways (Kerfoot and Sih 1987). In running waters, studies have generally focused on either the direct lethal impacts of fish predation on patterns of prey abundance (Allan 1982, Flecker 1984; Gilliam et al. 1989) or nonlethal effects of fishes resulting in spatial and/or temporal shifts in prey distribution and activity (Allan 1978; Cooper 1984; Kohler and McPeek 1989; Becker 1992). Little attention has been given to whether the dynamics of patch colonization are affected indirectly by fishes via the food web.

For example, fishes may exert strong indirect effects on insect abundance if the availability of resources important to invertebrates is modified by the presence of fish. Most studies to date have failed to show strong community wide lethal effects of vertebrate predation in streams (Zelinka 1974, 1976; Allan 1982; Reice 1983; Flecker and Allan 1984; Culp 1986; Reice and Edwards 1986).

However, the generality of these findings is uncertain because reductions in prey abundance have been observed in several cases (Flecker 1984; Cooper 1988; Gilliam et al. 1989). Clearly, the existing understanding of the role of predators in structuring stream communities is limited by a strong bias towards studies of fast-flowing, stony bottom streams in the north temperate zone, where most fishes feed on stream invertebrates (Allen 1969).

In tropical systems the importance of fishes as determinants of stream insect assemblage structure is unknown, but it appears to be quite different from the temperate zone. In the tropics, fishes can be exceedingly diverse (Roberts 1972; Lowe-McConnell 1975) and often occupy trophic guilds that are rare or nonexistent for fishes of temperate streams.

One striking difference between tropical and temperate freshwater systems is that detrital and algal-feeding fishes are widely distributed components of tropical ichthyofaunas (Goulding et al. 1988), whereas few fishes derive their nutrition from these sources in temperate waters (Bowen 1983). Fishes that feed on detritus and algae can also represent a significant portion of the biomass in tropical and subtropical streams, especially in South America.

For example, Bonetto (1986) reported that the detrital-feeding characoid *Prochilodus platensis* alone comprised up to **50–60%** of the ichthyo-mass in the Rio Parana, with standing crops **>1000 kg/ha**. This abundance of detrital and algal-feeding fishes in South American streams suggests that, in addition to acting as predators of stream insects, fishes may be important as macroconsumers that exploit resources utilized by many taxa of benthic invertebrates.

Furthermore, Power (1984a, 1990) has shown that grazing armored catfish are important consumers of algae and sediments in Panamanian streams, and influence the abundance of these resources during the dry season. Stout and Vandermeer (1975) posited that the importance of fish predation may be more pronounced in tropical than in temperate running waters.

They suggested that a more active role of predation and other biotic interactions in the tropics may result in latitudinal differences in both species-area curves and abundance of lotic insects. Species richness was reported to be higher in a series of tropical streams than in temperate streams, leading them to propose that keystone predation by insectivorous fishes could potentially maintain higher species diversity in low latitude systems. Experimental on the relative importance of direct vs. indirect effects of fishes on patch colonization by a neotropical stream insect assemblage. Research evidences have showed that direct effects of predation by a guild of insectivorous characids which feed largely on stream insects are relatively weak, when compared to indirect effects that algal and detrital-feeding fishes exert through modifying epibenthic resource levels. These indirect effects demonstrate a potentially more varied role of fishes in the tropics, and show that nonlethal effects of fishes need to be examined when considering the structuring mechanisms important in neotropical stream communities (Tables 3.7, 3.8, 3.9, 3.10, and 3.11; Fig. 3.2).

3.22 Biotic Integrity Index (IBI): Developing of Fish-IBI

Biotic integrity refers to the capacity of biotic community to maintain structural balance and to accommodate environmental variation (Karr 1981). Since Karr (1981) developed index of biotic integrity to assess river health, many scholars had modified and extended this index system (Karr et al. 1986; Hughes and Oberdorff 1997; Barbour et al. 1999; Simon and Sanders 1999; Joy and Death 2004; Zhu and Chang 2008; Lyons 2012; Krause et al. 2013). Algae, benthic invertebrates, and fish have been used to evaluate the biotic integrity of aquatic system (Ruaro and Gubiani 2013).

3.22.1 Fish as a Model for Devising IBI

The aquatic ecosystems including that of rivers and streams are affected adversely by the human activity to a large extent across the world during the previous few decades at a higher rate than at any other time in history (NRC 1992). All of these activities cause eco-degradation of the habitats by deteriorating the qualities of water and soils and thereby disrupt the normal interactions among the fish species within the biotic community of the rivers and streams. Fish communities are often used to detect such impairment of the ecological conditions of the rivers and streams as most of the fishes being the sensitive biotic components respond to a range of biological, physical, and chemical disturbances (Karr 1981). The structure of a fish community of a river is determined on a local scale by a number eco-hydrological factors such as

Table 3.7 Biological indicators are required to be identified to be used in the assessment of ecological status of an water body with the objectives of ensuring protection of human health, and conservation of biotic integrity, other bioresources. An integrative index approach should include representative metrics across a range of these levels

Bioassay – procedure of exposing test organisms, in a laboratory setting, to various concentrations of suspected toxicants or dilutions of whole effluent: Single species test ;Multispecies (microcosm, mesocosm) tests
Biosurvey – process of collecting a representative portion of the organisms living in the target water for an ecoassessment of biotic community: selection of indicator species based on Individual/species population; Histophysiological analysis for bioaccumulation
Biomarkers- moleular and biochemical entities
Yield assessment: biomass and growt rates
Morpho-anatomy: external or internal
Behavior
Abundance Density of population and population size all bold
Frequency and Intensity of Disease or parasitism frequency
Indicator taxa or guilds or Species richness or diversity in Community and Ecosystem
Tolerants and Sensitive species : Relative abundances among species; Dominant species or Opportunistic species.
Community trophic structure
Extinction
Function attributes : Production/respiration ratio ;Production/biomass ratio
Biogeochemical cycles and Budgeting of nutrient
Landscape and Cumulative effects across landscapes : Habitat fragmentation , patch geometry and Linkages among patches

depth, volume current and velocity of water, size of substrate particles, cover, and temperature (Rabeni and Jacobson 1993), which also may alter biological interactions.

Index of Biotic Integrity (IBI) comprising of five community metrics have been applied and evaluated for several watersheds along river ecosystems mostly in the Midwestern USA and revealed their dependence on the diversity of a number of fish species. The species richness and adaptability of fishes must be adjusted along with the changes of with stream size or zoogeography. The relationships of fish species richness with the changing stream sizes, derived from the long-term research monitoring data of fish community of some selected watersheds, are used to predict attributes of "**excellent**" fish communities, assigning scores of **5** of **12 IBI** metrics to be used for comparison (Table 3.4).

Fish as good model for deducting **Index of Biotic Integrity (IBI).** Owing to high visibility to the public, high sensitivity to water quality, and the top position in the food chain (Karr 1991), fish assemblages were considered to be an appropriate method for assessing river health (Karr 1999; Karr et al. 2008), which is more comprehensive than physical and chemical indices (Bozzetti and Schulz 2004).

Table 3.8 Metrics used to assess biological integrity of benthic invertebrate communities

A. Invertebrate Community Index (ICI) (after Ohio EPA 1988[a]). Ratings of 6, 4, 2, and 0 are assigned to each metric (on a comparative basis exceptional, good, slightly deviates from a good, or strongly deviates from a good community)
1. Total number for taxa
2. Total number of mayfly taxa
3. Total number of caddisfly taxa
4. Total number of dipteran taxa
5. Percent mayfly composition
6. Percent caddisfly composition
7. Percent tribe Tanytarsini midge composition
8. Percent other dipteran and noninsect composition
9. Percent tolerant organisms
10. Total number of qualitative EPT taxa
B. Rapid Bioassessment Protocol III (after Plafkin et al. 1989). Ratings of 6, 3, and 0 are given based on values of each of the metrics with 6 being high quality and 0 being heavily degraded site
1. Taxon richness
2. Family biotic index
3. Ratio of scraper/filtering collector
4. Ratio of EPT and chironomid abundances
5. Percent contribution of dominant family
6. EPT index
7. Community loss index
8. Ratio of shredders/total

[a]Metrics 1–9 based on artificial substrate sampler, metric 10 based on qualitative strain sampling
EPT – taxa in the Ephemeroptera, Plecoptera, and Trichoptera
Metrics 1–7 based on qualitative riffle/run sample; metric 8 based on leaf-pack (CPOM) sample

The first usage of fish-based index of biotic integrity (**F-IBI**) for stream assessment was by Karr who evaluated the stream health in the Midwest America. Later, the **F-IBI** evaluation method was widely used in the fundamental research of river ecosystem, water resource management, aquatic system evaluation, and policy and law formulation (Barbour et al. 1999; Belpaire et al. 2000; Schleiger 2000; Cassner et al. 2003; Dauwalter et al. 2003).

A careful selection of the metrics was made with an aim to involve almost all components of the fish communities (species richness, composition, habitat use and trophic status), in order to record and represent different responses, so that all increased ecological information ensure more acceptability of the index (Barbour et al. 1999).The research data pertaining to species richness and abundance were later used for calculation of biological metrics. Dominance was calculated using Simpson index with the computational software and values close to zero indicate low dominance.

Based on literature data and present study, fish assemblages in rivers under study were classified according to its richness (Native Species), composition and

Table 3.9 Total index of biological Integrity (IBI) scores, integrity classes, and the attributes of those classes. (Modified from Karr 1981)

Total IBI score (sum of the 12 metric ratings)	Integrity class of site	Attributes
58–60	Excellent	Comparable to the best situations without human disturbance; all regionally expected species for the habitat and stream size, including the most intolerant forms, are present with a full array of age (size) classes; balanced trophic structure
48–52	Good	Species richness somewhat below expectation, especially due to the loss of the most intolerant forms; some species are present with less than optimal abundances or size distributions; trophic structure shows some signs of stress
40–44	Fair	Signs of additional deterioration include loss of intolerant forms, fewer species, highly skewed trophic structure (e.g., increasing frequency of omnivores and green sunfish or other tolerant species); older age classes of top predators may be rare
28–34	Poor	Dominated by omnivores, tolerant forms, and habitat generalists; few top carnivores; growth rates and condition factors commonly depressed; hybrids and diseased fish often present
12–22	Very poor	Few fish present, mostly introduced of tolerant forms; hybrids common; disease, parasites, fin damage, and other anomalies regular
……	No fish	Repeated sampling finds no fish

Dominance (Kar 1981; Ferreria and Casatti 2006; Snyder et al. 2003; Lyons et al. 1995; Harris 1995), trophic structure (Snyder et al. 2004, 2005; Harris et al. 1999, 2000), and reproductive habitat preference (Snyder et al. 2006). Twelve metrics composed the IBI when Karr first proposed it in the year 1981 which were subsequently reorganized depending on habitat features, biogeographical regions, and environmental factors in different parts of the world (Kar and Chu 1999).

3.22.2 Ecological Applicability of F-IBI

Fish-based biotic integrity index (F-IBI) can also be used as a monitoring and evaluation tool to identify streams and small rivers where restoration activities are needed and to monitor trends in biotic integrity and biodiversity over time. This has been the most common use of the index of biotic integrity, although primarily in the context of environmental protection rather than that of conservation biology. Long-term monitoring and evaluation of conservation activities are an important part of

Table 3.10 Total index of biological Integrity (IBI) scores, integrity classes, and the attributes of those classes (modified from Karr 1981)

Total IBI score (sum of the 12 metric ratings)[a]	Integrity class of site	Attributes
58–60	Excellent	Comparable to the best situations without human disturbance; all regionally expected species for the habitat and stream size, including the most intolerant forms, are present with a full array of age (size) classes; balanced trophic structure
48–52	Good	Species richness somewhat below expectation, especially due to the loss of the most intolerant forms; some species are present with less than optimal abundances or size distributions; trophic structure shows some signs of stress
40–44	Fair	Signs of additional deterioration include loss of intolerant forms, fewer species, highly skewed trophic structure (e.g., increasing frequency of omnivores and green sunfish or other tolerant species); older age classes of top predators may be rare
28–34	Poor	Dominated by omnivores, tolerant forms, and habitat generalists; few top carnivores; growth rates and condition factors commonly depressed; hybrids and diseased fish often present
12–22	Very poor	Few fish present, mostly introduced of tolerant forms; hybrids common; disease, parasites, fin damage, and other anomalies regular
……	No fish	Repeated sampling finds no fish

No score can be calculated where no fish were found
[a]Sites with values between classes assigned to appropriate integrity class following careful consideration of individual criteria/metrics by informed biologists

conservation biology, and the index of biotic integrity is a powerful, quantitative tool for assessments at the community/ecosystem level.

Fish-based index of biotic integrity (FIBI) is widely used to assess river ecosystems. With survey data from the Yellow River fishery resources in the **1980s** and **2008**, fish composition and abundance, vertical distribution, trophic structure, reproductive guilds and tolerance in the river's upstream, midstream, downstream, and estuary were examined, and **F-IBI** systems were established for each reach to assess river ecosystem health. Results showed that compared to the 1980s, the number of fish species in **2008** sharply declined in the midstream and downstream reaches. In contrast, the percentage of benthic fish species decreased in upstream and estuary, the number and percentage of omnivorous species decreased in all reaches, and percentage of tolerant fish species increased **15** times in upstream but decreased in midstream and downstream. The **Fish-based IBI** scores in the four reaches in the **1980s** were all higher than those in **2008** and decreased from upstream to estuary. The healthy conditions of the rivers, in respect of the water quality

Table 3.11 Guidelines for rating and interpreting index of biotic integrity scares for streams and small rivers in west-central Mexico, modified from Karr et al. (2008); Lyons et al. (1995); Lyons (2012)

Score	Rating	Fish community attributes
70–100	Good	Comparable to the best situations with the least human disturbance. Total and water-column species richness is at or near the maximum expected for the size of stream, and overall fish abundance is high, with a full array of age and size classes. Both benthic and water-column species are common. Sensitive species are present, and tolerant species and exotics do not dominate. Herbivores and/or carnivores are common. The majority of fish are native livebearing species. Nearly all fish are in good physical condition
45–65	Fair	The fish community shows some influence of environmental degradation. Total and water-column species richness in somewhat below expectations, and benthic and sensitive species are often uncommon or absent. Tolerant and exotic species are common, and omnivores dominate. The majority of fish may not be native, livebearing species.
0–40	Poor	The fish community is greatly modified by environmental degradation. Total and water-column species richness is low. Overall fish abundance on also low, and most fish are small. Benthic and sensitive species are usually absent. Nearly all fish are exotics or tolerant omnivores, and most individuals are not native, livebearing species. Fish in poor physical condition nay be relatively common
No score	Very poor	Environmental degradation . . .. . . decimated or eliminated the fish community. Thorough sampling reveals few or no fish and the index of biotic integrity cannot be calculated

parameters, were assigned with the **F-IBI** scores in the **1980s** were “**good**,” “**fair**,” “**poor**,” and “**fair**” from upstream to estuary and “**degraded**” to “**poor**” in all the reaches in **2008**. This indicated that the river ecosystem has degraded from the **1980s** to **2008** (Li et al. 2018). In the studies of Karr (1981), Karr et al. (1986), Fausch et al. (1990), and Liu et al. (2010), the scores were classified into **6** grades indicating “**Excellent**” to “**No fish**” from high score to low score when the score values range from **0** to **60** (Tables 3.7, 3.8, 3.9, 3.10, and 3.11).

3.23 Relevance of Trophic Structure in Assessing Ecological Changes

Identification and enumeration of the number and percentage distribution of different feeding categories of fish such as herbivorous, omnivorous, and carnivorous fish in each reach through long term decadal survey in many rivers of both temperate and tropical countries have revealed the number and percentage of omnivorous fish species were higher in most of the ecozones followed by carnivorous fish, and then by herbivorous fish. This finding can be interpretated by the availability of detritus and other decomposition products throughout the entire stretch of rivers whereas the availability of green biomass as the food of fishes is restricted mainly because of the influence of two ecological parameters **viz**. light and turbidity. However, the number and percentage of omnivorous fish species in each reach showed a trend of decrease from the upstream to the estuary end in tune with the changes of river ecology.

3.23.1 Reproductive Guilds in the Temporal and Spatial Scales

The entire fish community can be divided based on the reproductive structures, potential, and seasonality across the riverine tracts from the upstream to downstream .The number of semipelagic egg species and deposit-egg species showed similar spatial and temporal trends, with the largest occurring in the middle reach of 1980s. The number of pelagic egg species and viscid-egg species also showed similar spatiotemporal trends, with the maximum values in the downstream in both the **1980s** and **2008**. In terms of the percentage of semipelagic egg species, zero is found in the estuary of **1980s**, while the percentage increased to **23.53%** in **2008**. In the upper reach in the **1980s**, pelagic egg fishes were not found, while they occupied **9.52%** in 2008 (Li et al. 2018).

3.23.2 Distribution of Tolerant Species

In the two surveys, the tolerant species account for the biggest part, followed by medium species, except for the upstream and midstream in the **1980s**. In the **1980s**, the number of sensitive fish species reached a maximum, with **13** species in the midstream, while only **3** species were found in **2008**. The number of tolerant species was **82** and **74** in the **1980s** and **2008**, respectively. In terms of percentage, the number of tolerance species increased from **1.22%** in evaluation result is "**fair**" and "**poor**," respectively; the **IBI** values for downstream are **20** points and **18** points and both are evaluated as "**poor**"; and in the estuary, the IBI values are **26** points and **16** points and are evaluated as "**fair**" and "**poor**". In **2008**, the **Fish-based IBI scores** experienced less variation than that of the **1980s**. Generally, the fish biotic integrity of the Yellow River is better in the **1980s** than that of **2008**.

3.23.3 Interpretation of Long-Term Research Monitoring Based on Fish-Based IBI

Considering all those research information, it can be concluded that the Fish-based **IBI** evaluation results throw light with regard to the changes of ecological conditions [water quality parameters such as chemical oxygen demand (**C.O.D.**); biochemical oxygen demand (**B.O.D.**); nutrients; **pH**; etc.] of the Yellow River from the **1980s** to **2008**, This study showed that for all reaches of the Yellow River, the fish index of biotic integrity in the **1980s** were better than in **2008**, which indicated that the river ecological system suffered more anthropogenic disturbance in **2008**.

This study also found that **F-IBI** values presented a decrease from the upstream to the estuary, indicating that the ecological integrity of fish decreased from upstream to estuary. The reason may be that there is sufficient water quantity with little sediment concentration in the upstream which creates better fish biotic integrity (Miao et al. 2010, 2011), while in the midstream and downstream of heavily populated area, human diversion activities led to insufficient water erosion on the riverbed and hence large sediment concentration (Jiang et al. 2004). The **F-IBI** assessing results revealed that ecological condition has decreased from "good" in the upstream in the **1980s** to "**poor**" in **2008**, which agreed with the serious environmental degradation in upstream in the river (Feng et al. 2006).

The river ecological destruction may be derived from a variety of reasons.

First, less precipitation and warmer climate in the Yellow River resulted in dramatic decrease of stream flow from the **1980s** to **2008** in the middle and lower reaches (Miao et al. 2012; He et al. 2013).

Second, water consumption from irrigation enhanced significantly with this period

of time, mainly due to irrigation area increase. For instance, irrigation area increased from **4 9106 ha** in **1980** to **4.8 9106 ha** in **1995** (He et al. 2013). It is estimated agricultural irrigation accounts for the **85%** of whole water consumption (Xu and Ma 2009).

Third, the population in the Yellow River basin increased from **84 million** in **1982** to **105 million** in **2000**, which results in increased human stress on the Yellow River, such as increased water consumption and contamination (He et al. 2013).

Bearing the aforementioned reasons for ecosystem degradation in mind, it is therefore practical to propose several corresponding measures to mitigate the severe scenario happening in the past and perhaps in the future for the Yellow River. **First**, a unified plan should be proposed and followed rigorously to utilize water resources harmoniously. **Second**, public awareness of water conservation should be strengthened. **Third**, new irrigation techniques with increased water conservation capability should be popularized. Fourth, more wastewater treatment plants should be built to collect and treat domestic sewage. Fifth, stricter regulations on industrial wastewater treatment should be implemented.

3.23.4 Limitations of the Study and Future Work

The method developed in this study showed feasible for ecological assessment of the Yellow River. However, several limitations should be taken into consideration when interpreting the F-IBI results.

First, there is no reference condition free from anthropic pressure in the present study. Alternatively, we established the best reference condition based on the best value observed among all sampling sites for each metric, and the worst reference condition based on the worst value among all sampling sites for each metric as many researchers (Fausch et al. 1984; Bozzetti and Schulz 2004; Stoddard et al. 2006; Liu et al. 2010) did before. Because we establish scoring criteria based on the best reference condition among sampling sites which might have been disturbed, the F-IBI values for each river reach might be overestimated (Shearer and Berry 2002).

Second, the number of sampling sites within each reach of the Yellow River might be insufficient. For example, there are only seven sampling sites in the long distance of the upper stream. Study of Yoder and Rankin (1995) revealed that at least 35–40 sampling sites might be required to establish a reliable **F-IBI** index.

Third, lack of metric screening process might result in introduction of bias in the **F-IBI** system. The metric screening process is often performed in previous studies, based on various statistical methods and sampling data, to choose metrics with the most discriminant capability and to avoid redundancy. Regrettably, we do not have sufficient data to perform statistical screening. The metrics in this study are determined based on the original **IBI** system and other studies elsewhere,and screened based on similar studies on Chinese rivers and professional judgment, which might exhibit bias on some ecological attributes.

In short, the **F-IBI** developed in this study is the first study in the second largest river in China, but it should be regarded as a preliminary version. Further studies should conduct more sampling along the Yellow River. Systematic and comprehensive analysis is needed for the ecological and physicochemical assessment of the Yellow River (Wang et al. 2010).

3.24 Developing of Physical Habitat Index

Biotic assemblages and bio-integrity are intimately connected and are regulated by the structural properties of physical habitats (Gorman and Karr 1978) which include current velocity (Poff and Allan 1995), water temperature (Wang et al. 2003), loading of organic matter (Gregory et al. 1991), depth and cover, and appropriate substrates for spawning (Berkman and Rabeni 1987; Hughes et al. 2006). Therefore, physical habitats act as key player in attracting and providing suitable living space for a given species at that particular location and thereby determine the structural and functional pathways of stream ecosystem by accommodating more organisms. They are used for monitoring and in the restoration processes by predicting potential fish presence and abundance and identify limiting factors in stream habitat (Wang et al. 1998). Diverse assemblages and higher abundances of organisms as seen in diverse stream habitats (Gorman and Karr 1978) have established the view that physical habitat directly influences the fish assemblages, whereas changes in the landscape impose indirect effects on fish assemblages operating via intermediate, ecological pathways (Poff 1997).

For the assessment of the physical habitat, a visual-based habitat approach was conducted. Many protocols are applied around the world, all of them including descriptors which describe the stream micro/macro features, riparian condition, and bank structure (Barbour et al. 1999). Scores were ascertained according to premonitored reference conditions, and thereby separating study sites into high-gradient and low-gradient reaches. With an aim at reducing the subjectivity, the same person was assigned the responsibility to collect information and analyzing the same for an overall evaluation of all sites. All descriptors were assessed with properly structured questionnaires and rated their opinions on a numerical scale of **0–20** for each sampling reach. The sum of all scores represented three habitats integrity categories (pool substrate, velocity/depth combination, and Riparian vegetation zone width) of the physical habitat index (PHI).

3.25 Impact of Habitat Fragmentation on Fish Biodiversity: A Cause of Extinction

Land-use change, which often results in habitat fragmentation, conversion or degradation, is one of the global anthropogenic causes of past and projected loss of species (Kareiva et al. 1993; Sala et al. 2000).

The main consequence of habitat fragmentation is the subdivision of a population into several smaller units. Theory predicts that the smaller the size of a population, the higher the probability of its extinction (Lande 1993). Thus small populations occupying small fragments may be faced with a high risk of extinction over relatively short, ecological timescales unless they are rescued by immigration.

Quantifying the relationship between fragment size and extinction probability is of major importance for predicting the consequences of ongoing and future habitat fragmentation due to human activities, particularly for species that have a low dispersal ability. The faunal relaxation approach, pioneered by Diamond (1972), is probably the method that has most frequently been used to indirectly estimate extinction rates.

The basic idea of this approach was to compare extant species richness per island with richness predicted at the time of fragmentation. According to the theory of island biogeography, species richness per island should decrease after fragmentation because immigration is stopped or reduced. This process is known as faunal relaxation (Diamond 1972).

The temporal change in richness has been considered primarily the result of extinctions in the presence of speciation and colonization. Using a similar framework, other systems that were fragmented during the climate change that ended the last glacial period have served as empirical models of the consequences of fragmentation for species richness (Brown 1971; Case 1975; Wilcox 1978; Heaney 1984; Lawlor 1986; Patterson and Atmar 1986; Richman et al. 1988; Lomolino et al. 1989; Foufopoulos and Ives 1999). To anticipate the erosion of biodiversity within this highly vulnerable group, a better understanding of the natural and human drivers of population extinction is needed. In contrast, the negative impacts of habitat fragmentation (dams) on many aspects of fish biology and ecology (Fukushima et al. 2007) are clearly identified, few empirical estimates of population extinction rates due to fragmentation exist (Morita and Yamamoto 2002). Establishing an empirical relationship between surface area occupied by a population and extinction rate is a first step towards a better prediction of the impact of habitat fragmentation on future river fish biodiversity loss.

3.26 Immigration and the Strength of Trophic Interactions

In the process of trophic interaction involving fish as central biotic component, the role of grazers have been noted to be more effective in shaping the structure and function of river ecosystem than the predator fishes. It has also been found that the immigration may be an important mechanism compensating for prey consumption in some running water systems (Flecker 1984, also see Allan 1983; Cooper et al. 1990). Because lotic organisms live in a moving-water medium, the potential for immigration via water-column transport (drift) can be great, especially in fast-flowing conditions.

The importance of immigration on community structure should depend in part on qualitative features of consumer effects. If the main effect of consumers is the direct consumption of prey (predation), then prey depletion may be offset by immigration. In contrast, if consumers indirectly affect community structure by reducing patch quality (by algivory or detritivory), the potential for immigration to overshadow consumer effects may be weak.

This is because lowering patch quality should affect patterns of habitat choice, and should reduce residency by increasing insect emigration rates, even when immigration is high. Thus, differences in the interplay among a variety of processes (consumption, microhabitat quality, immigration, and emigration) may explain disparities in the strength of trophic guild interactions on stream community structure.

In contrast, strong effects of fish predation have been observed in small, slow-flowing streams (Cooper 1988; Gilliam et al. 1989). In general, grazers have been shown to exert dramatic effects on community structure, influencing algal and sediment resources. Although studies involving algivorous fishes are limited to slow flow conditions where invertebrate immigration may be low (Power 1984a, b, 1990; Power et al. 1985, 1988; Matthews et al. 1986, 1987), Finally, several workers (Bdhle 1978, Kohler 1985) have shown experimentally that emigration (drift) is higher when algal resources are low. Therefore, by lowering resource abundance and hence microhabitat quality, grazers may indirectly increase insect emigration rates.

The research findings based on long term ecological survey suggests that a variety of fish trophic guilds play an important role in the organization of neotropical stream communities. In temperate streams, however, most examples of biotic interactions have involved invertebrate species (Peckarsky and Dodson 1980; Hart 1983; Lamberti and Resh 1983; McAuliffe 1984; Walde 1986; Hawkins and Furnish 1987). Even though the role of grazing and detritivorous fishes has clearly been underestimated in temperate freshwater systems, and in some cases has been shown to be quite strong (Power et al. 1985, 1988; Matthews et al. 1987), trophic diversity and biomass do not begin to rival that of tropical ichthyofauna (Roberts 1972). These observations make it tempting to hypothesize that latitudinal gradients in fish diversity are accompanied by functional shifts in community control. Quite possibly the roles of insects in temperate streams are replaced by larger, motile fish consumers in the tropics.

The consequences of switching from insect-to-fish-dominated systems have not been well explored but should have some important implications for community structure. First, fishes as macroconsumers process large volumes of organic material as a function of their body size. This is particularly true in the tropics where large size is accompanied by high abundance and elevated metabolic rates.

3.27 Global Warming Mediated Stress on Fish and Fisheries: An Ecobiological Assessment

3.27.1 Overall Impact of Climate Change on the Aquatic Ecosystem

The continuous increase of temperature due to global warming and associated climate change has become a growing threat to biodiversity all over the world (IPCC 2000). Such increased temperature-mediated stress hampers the biological functioning of a species at its molecular, physiological, and biochemical levels and thereby alter distribution patterns as well as community interactions (Das et al. 2004; Chakraborty et al. 2014; Maiti Dutta et al. 2014, 2018). Intergovernmental Panel on Climate Change (IPCC 2000, 2007) have concluded in their assessment reports that so many other micro and macro-ecological factors and processes such as changes in the land-use, especially deforestation leads to fragmentation of the habitats obliteration of ecological corridors, blockage of migration routes, massive erosion in the river basins and catchment areas, alterations of hydrological cycles mainly due to modification of the intensity of winds flow, quantum and seasonality of rainfall, and retardation of freshwater flows from the rivers to the sea paving the way for increasing the salinity, turbidity, thermal stratification, water column stability, decrease the nutrient availability to euphotic zones and hampering the primary productivity. All of these ecological changes result in acidic and hypoxic conditions, both in the surface and subsurface of the water bodies, especially in the coastal wetlands by reducing the pH, and dissolved oxygen, respectively (Schallenberg et al. 2001; Flöder and Burns 2004; Justic et al. 2005; Halpern et al. 2008, Chakraborty, 2014). In addition, continuous generation and supply of nutrients are retarded and the reduced supply of sediments to the estuarine-coastal ecosystem due to damming and channelization also cause different ecological perturbation, mainly for the growth and propagation of flora and fauna (Syvitski et al. 2005). The biodiversity of the confluence of the river and sea, the coastal zones experience more vulnerability due to the impact of climate change mainly because of warming of water, hypoxia, acidification, least availability of nutrients, higher turbidity coupled with least penetration of sunlight, sea-level rise, more possibility for the spread of diseases, and bioinvasion (Archer and Rahmsterf 2010; Chakraborty et al. 2014; Chakraborty 2018). **IPCC** (2007) has also reported that freshwater ecosystems and inland fisheries [ninety percent (**90%**) in Africa and Asia] (FAO 2006) are vulnerable and impacted considerably by the global warming-mediated climate change in conjunction with the undesirable anthropogenic intervention on water resources, especially in the tropics with reduced and unpredictable rainfall in conjunction by damming and abstraction of water for agricultural which result in considerable shrinkage of fresh water bodies (Christensen et al. 2007). Coincidental ecological changes covering a vast part of the world trigger multidimensional ecological responses in respect of the alterations, species diversity, distributions, food web processes, productivity, and other microevolutionary processes mainly by hindering natural and evolutionary programmed and predesigned life cycle and reproductive process (spawning, recruitment, and survivility of spawns) by climate variability (Harley et al. 2006).

The increase of water temperature due to global warming, trigger the bloom of phytoplankton, some species of which initially exhibit adaptive efficiency to survive in low-nutrient conditions and getting the benefits in their metabolic rates initially from the increased temperature. Besides, this eco-biological development facilitates the production rates of zooplankton with the rise of temperature, experiencing a two to fourfold increase in the rates of multiplication (Watson et al. 1997) and result in the long-term increases in fish production despite sustaining the negative impacts because of the changes in the species composition of preys (Watson et al. 1997). Increasing trends of temperature have been found to modify the previous spawning behavior of fishes which thereby fails to synchronize with the phytoplankton blooms, resulting in a temporal mismatch between larval production and food supply (Philippart et al. 2003). Observations of zooplankton and high trophic level indices (fish, birds) showed consistent patterns that are strongly correlated with large-scale year-to-year and decade-to-decade ocean climate fluctuations. The change in developmental timing of zooplankton cannot be explained solely by the physiologically accelerated process, but strongly coincide with seasonal environments where the increased temperature is supposed to act as an environmental indicator contributing to mismatch timing (Mackas et al. 2001). Differential responses of different species within the plankton community and their consumers (fishes) suggest that the increase of water temperature can cause alteration of the trophodynamics in the freshwater ecosystems and result in predator-prey mismatch. Temperature-mediated changes in the timing of life history of plankton impart physiological stresses and result in phenology changes leading to the failure in the recruitment success and therefore cause a decline of the population density of many aquatic species, particularly at the "**extremes of species**" ranges, and for shorter-lived species.

In addition, both positive and negative effects on fisheries and aquaculture systems are affected by the disruption of normal physiological functioning and seasonality of particular biological processes, alteration of the eco-dynamics of both marine and freshwater food webs, and uncertain fishery development with major decline in fish production. All such developments facilitate more bioinvasion coupled with higher risk for vector-borne diseases. Changes in freshwater systems due to the impact of climatic changes result in a pole-ward shift of different species of fishes, plankton, and algae alongside that of ocean water (Archer and Rahmsterf 2010), and this dispersal phenomenon depend on the ability of freshwater species **to "move across the landscape,"** utilizing the available dispersal corridors which are mostly disturbed by the activities of human beings (Poff et al. 2002). The growth and recruitment of fishes are indirectly affected by the nonavailability of good quality plantonic foods (Taylor and Wolff 2007).

Global warming has been increasing the intensity of monsoon winds and accelerates the intensification of the hydrological cycles of the tropical world and thereby influence the limnological processes as well. Snow and glacier melting of ice in the mountains of Asian countries increase the flows of the large rivers such as Ganges, Indus, and Brahmaputra in India and Mekong in China which support fisheries in several of their tributaries and floodplains. Freshwater ecosystems are subjected to experience more to the inundation problems as a result of climate change. For flood due to the changes in timing, intensity, and duration of floods, which in turn enable the fish species to harvest the benefits of getting more foods and habitat heterogeneity by adapting themselves for effective migration, spawning, and transport of spawning products.

3.27.2 Experimental Evidence of Impact of Temperature on the Eco-Biology of Major Carp Species (Order Teleost: Class Pisces)

In order to cope up and to survive in a changing ecological condition to meet up different eco-ethological requirements of fishes such as migration, foraging, breeding, nurturing of juveniles alongside maintaining of normal metabolic activities and growth. The biochemical, and physiological activities of all poikilothermal animals, including fishes are influenced considerably by temperature fluctuations in their environments and behavioral and physiological adaptabilities against such environmental odds ensure their survivality and growth. (Prosser and Heath 1991). Temperature being the most important ecological variable enhances metabolic rate and thereby increase the oxygen demand and the susceptibility of invasiveness and virulence of microbial pathogens responsible for causing several pathophysiological disturbances within the infected fishes (Wedemeyer et al. 1999). Extreme fluctuation of temperature has been found to impose cellular, morphological, histological, physiological, and biochemical stresses on the adults and juveniles of fishes (Tort 2011, Egginnton and Sidell 1989; Das et al. 2004, 2005, 2006a, b, 2009, and 2014).

Global mean temperature is expected to be increased by **1.5 °C** to **4.5 °C** over the next half century because of the continuous emission of greenhouse gases resulting to global warming (Hounghton and Woodwell 1989). As fishes (both marine and freshwater) being the poikilothermic in nature are more susceptible to the harmful impact of increased temperature because their biological functions are critically dependent on environmental temperature. Thermal tolerance of aquatic animals is determined acclimation temperature and duration of acclimation (Manush et al. 2004).

Therefore, the eco-biological reality of the thermal stress on the growth and propagation of aquatic life, especially fishes are seemed to be aggravated in view of the ongoing increasing trend of temperature due to global warming which has necessitated to undertake new efforts to understand the inherent and acquired adaptabilities of the tropical fishes in respect of their thermal tolerance to combat the harmful consequences on fish health (Das et al. 2004, 2005, 2006a, b, 2009, and 2014).

Several experimental studies were undertaken using three freshwater and eurythermal Indian Major Carps (**IMC**) viz. *Labeo rohita, Catla catla, and Cirrhinus mrigala* as experimental test species to understand the impact of temperature changes on their physiology (metaboloic activity, oxygen consumption, etc.), biochemical parameters like sugars, vitamins, cortisols, lipids, and their fractional components etc., embryological developments and growth, roles of Heat Hock Proteins 70 (**HSPs 70**) in affording tolerability and mode of alterations of morpho-anatomical structures, especially, in view of global warming which together with the seasonal oscillation of water have synergistically imparted harmful effects on the natural survivality of fishes of tropical climatic conditions (Das et al. 2004, 2005, 2006a, b, 2009, and 2014). The experimental results have shown maximum power of tolerability of *C. mrigala* followed by *L. rohita* and *C. catla* against sharp but uniform fluctuation of temperature from **12 °C** to **40 °C** (Das et al. 2004). These findings have been explained by observing on the feeding habits of these carp species where the bottom feeders (*C. mrigala*) are physiologically more adapted to higher temperature mediated adverse ecological condition followed by the column feeders (*L. rohita*) and surface feeders (*C. catla*; least temperature tolerant species) (Das et al. 2004).

3.27.3 Experimental Evidence of Impact of Temperature on the Metabolic Activity of Major Carp Species (Order Teleost: Class Pisces)

Metabolism being a physiological process depicts the amount of energy which is spent by the living organisms for the growth and survivility. The metabolic rate of fish can be indirectly measured by knowing their rate of oxygen consumption which directly varies with the metabolic rate of fish, both of which represent indirect manifestations of the physiological changes in tune with the increasing temperatures mediated total aerobic metabolism (Brett 1964, 1979; Kutty 1968, 1981; Kutty and Mohamed 1975). This hypothesis has been substantiated by the experimental studies on the thermal tolerance and oxygen consumption of Indian Major Carps (*L. rohita, C. Catla*, *and C. mrigala*) where acclimation period, acclimation temperatures, and species-specific etho-physiological manifestations play significant roles (Das et al. 2004).

3.27.4 Experimental Evidence of Impact of Temperature on the Relative Oxygen Consumption (R.O.S) of Major Carp Species (Order Teleost: Class Pisces)

Most of the species of fishes exhibit increased rates of **Relative Oxygen Consumption** (**R.O.S**.) in response to increasing acclimation temperatures (Das et al. 2004). It has been found that the thermal tolerance ability of fish is mostly influenced by prior thermal exposure history or the ability of acclimation of the concerned fish species. Acclimation to changing seasonal conditions along with striking variability of ecological parameters including temperature let the fish to experience higher temperatures with more power of tolerance in summer than in winter (Bevelhimer and Bennett 2000). A research study by Das et al. 2004 has shown that **Critical thermal maxima** (**CTMax**) values of the respective fishes under the study were influenced by a variety of factors, especially differential rate of change of temperature during thermal exposure and process of tolerance studies, size, and condition factor of the experimental species which also corroborated the research observations of Baker and Heidinger 1996 as well as similar other studies on the impact of toxic chemicals on **CTMax** of fishes by Beitinger et al. 2000. Out of the three tested species, *C. mrigala* was found to be the most tolerant fish followed by *L. rohita* and *C. catla* and these results were explained by the differential power of different fish species to enjoy varied habitats and ecological niche (bottom-feeding and dwelling habits of *C. mrigala*) and thereby enabling the species to experience and enjoy species-specific higher thermal adaptation demonstrating remarkable resilience to altered temperature, especially for a prolonged time course and physiological changes during acclimation. Such abilities are supposed to enable **Indian Major Carps** to adapt and accommodate the increasing temperature condition which is being compounded by the ongoing problems associated with global warming (Das et al. 2004).

3.27.4.1 Heat Shock Protein 70 (HSP 70) Versus Metabolic Elasticity

The limits of thermal tolerance and oxygen consumption during the thermal acclimation process are determined by enzyme activities in different temperature regimes (Kita et al. 1996; Das et al. 2004). Besides, high protein along with other nutraceuticals act to counter stress due to thermal stress in fishes (Sudarman and Ito 2000; Zulkifli et al. 2004; Chung et al. 2005). **Heat Shock Protein 70 (HSP 70)** has been expressed by the living organisms in response to receiving certain heat shocks from a variety of stressors like thermal stress and also from environmental contaminants (Schlesinger et al. 1982; Iwama et al. 1998, 1999; Currie et al. 2000; Palmisano et al. 2000; Ming et al. 2003; Maiti Dutta et al. 2014, 2018) and play an important role in maintaining homeostasis (Sanders 1993; Forsyth et al. 1997; Feder and Hofmann 1999). **HSP70** proteins function by stabilizing unfolded protein precursors before assembly and help protein biogenesis by rearranging of protein oligomers, translocation of proteins into organelles, and refolding denatured proteins (Feige et al. 1996). In natural conditions, expression of heat shock proteins in fish varies with season (less during winter than in summer) and thereby can become an integral part of the adaptive mechanism of the fishes to the changing environment (Das et al., 2006).

3.27.4.2 HSP70 and Acclimatization

Acclimation of an organism is an adaptive mechanism against any long-term exposure of stressor which results in remodeling of cellular machinery to adapt to the new environment.

Acclimation to higher temperatures results in higher basal levels of **HSP70** (Dietz and Somero 1992) which in turn accelerate the rate of protein biogenesis under normal cellular conditions, and thereby promote the growth of organisms. Thus, enhanced protein synthesis requires increased amount of **HSPs** (Pal and Mukherjee 2003). Experimental studies with three major carp species (*L. rohita, C. Catla*, *and C. mrigala*) have revealed the expression of **HSP70** at **31 °C**, **33 °C,** and **36 °C** in increasing intensities after being regulated by the seasonal ecological conditions (expression of heat shock proteins in fishes was found to be less during winter than in summer), reflecting the acclimatization or adaptive mechanism of the concerned species to the changing environment. In the carp species, *L. rohita*, increased induction of **HSP70** was noticed with the increase of temperatures from **26°C** to **36 °C** by which they by adapting the acclimatization process. In addition, gradual but steady acclimation result in almost similar occurrence of induction of **HSP70** between **33 °C** and **36 °C** which points out the ability of the experimental fish species to adapt and withstand higher test temperatures (**33°C** and **36 °C**). A similar trend in the metabolic responses against the gradual enhancement of temperature from **33°C** and **36 °C** also indicates the adaptive strength of the **HSP70** of experimental fishes against slow, steady, and gradual increase of temperature i.e., thermal acclimation (Das et al. 2006). Therefore, induction of **HSP70** can act as the defensive mechanism in combating stress at higher acclimation temperatures resulting in unfavorable condition and thereby to maintain their homeostasis.

3.27.5 Impact of Increased Temperature on the Growth Rate a Freshwater Teleost Carp Species (*Labeo rohita*): An Experimental Evidence

Growth rates of fishes have always appeared as one of the most important biological attributes determining the economic profitability of any aquatic ecosystem due to higher biological productivity in terms of fishery resources. This developmental parameter of fish is also influenced and governed by biotic and abiotic factors (Brett and Groves, 1979). Out of so many, the temperature is considered as the prime abiotic factor, which directly regulates metabolism affecting all physiological processes in ectotherms such as procuring and initial processing of food, different metabolic pathways, production of energy, acquiring of nutritional efficiency, and nourishment of biomass (Brett 1979; Burel et al. 1996). Therefore, detecting suitable temperature profiles to ensure faster growth rates of fishes is very important for the effective management of fishery resources (Cui and Wootton 1988).

Nutrients of water in the form of nitrogenous compounds (**nitrite-N** and **nitrate-N** concentration) are increased with increasing acclimation temperatures. **Ammonia, the primary** nitrogenous excretory product of carps undergoes microbial decomposition to form the nitrogenous compounds. Higher density of biota thereby increases the level of ammonia which in turn causes a decrease of dissolved oxygen. The nutrients, play both positive and negative, roles in maintaining the low stocking density and arranging continuous aeration in order to avoid any confinement stress and ammonia accumulation in rearing tanks. An experimental study was conducted to understand the efficacy of temperature stress on food conversion ratio (**FCR**) and growth rates of one major carp fishe (*L. rohita*) by the simultaneous maintaining of all other water quality parameters to the optimum ranges during the growth study (Das et al. 2005).

Highest body weight gain (%) and lowest **FCR** were recorded at **31.1 °C** followed by **33.1 °C**, but such differences were not significantly different. These findings could enable to identify the suitable and optimum temperature range (**31.1 °C–33.1 °C**) to ensure higher growth of the commercially important carp species in the tropical freshwater ecosystem i.e., *Labeo rohita* (Das et al. 2005).

3.27.6 *Impact of Increased Temperature Elevation and Embryonic Development of Freshwater Indian Major Carps: An Experimental Evidence*

Embryonic development of the ectotherms are reported to have been dependent on the differential expression of certain genes and temperature (Ojanguren and Brana 2003). Embryogenesis in carps involving organogenesis and somatic growth with respect to yolk absorption, circulation system, gill development, ability to swim are controlled by enzymatic activities which are in turn regulated not only by the temperature but other ecological factors too, such as **pH**, dissolved oxygen, nutrient loads, etc. Over the years, attention has been focused on the thermal tolerance of embryos and larvae of fishes which have appeared to be more sensitive to the oscillation of temperature than adult fishes (Brett 1970), and therefore have been used for most of the thermal tolerance studies (Houde 1989; Pepin 1991). The embryos of fishes inhabiting in the temperate climate are noted to be more sensitive to temperature changes than the embryos of tropical fish species (Hokanson and Kleiner 1974; Irvin 1974; Budington et al., 1993). Embryonic development is a complex process in which cellular differentiation and proliferation occur simultaneously experiencing different rates and are regulated directly by the temperature (Gould 1977; Hall 1922). Although increased temperature directly enhances the developmental rate of embryos, proper development only occur within the acceptable thermal limits which are narrower for early stages and retardation of growth takes place in the thermal limits suitable for the adults (Elliott 1981; Cossins and Bowler 1987; Atkinson 1996).

The experimental study on the selected carp species inhabiting in the tropical freshwater ecosystems has revealed that early embryonic stages are steno thermal in comparison to the advanced ontogenic phases of *L. rohita* (Das et al. 2004; Chatterjee et al. 2004), which also corroborates the findings of similar studies on other species (Elliott 1981; Cossins and Bowler 1987). Low temperatures were identified to cause hindrances of the normal growth (from the point of fertilization until hatching of the fish species) and retard the developmental process while high temperatures accelerate embryonic development (Lasker 1964; Blaxter 1981; Pepin 1991; Hart and Purser 1995; Hamel et al. 1997), which agrees with the research findings with the present study at four different temperatures (**26 °C, 31 °C, 33 °C,** and **36 °C**) displaying consistency in the embryonic growth patterns (Das et al. 2005). Reduction in hatching percentage with the formation of unhealthy embryos in later stages at **36** °C suggest non-suitability of the rearing temperature which appeared to be well above the tolerance limit for proper development of the eggs and fries of *L. rohita* or might have been due to the less production of adequate enzymes in the required amount for hatching (Reddy and Lam 1991). Higher hatching rate at **26 °C** and **31 °C** also indicates the suitability of these temperature ranges for the purpose of incubation (Das et al. 2005). The optimal temperature for incubating the eggs of *L. rohita* at **31 °C** considering the rate of development and hatching percentage is found to be higher in the present study than earlier reports on the same carp species by Ponnuraj et al. (2002).

3.27.7 Biochemical Responses of Freshwater Indian Major Carps against Temperature Stress

Temperature, being a pronounced ecological variable determining the interaction and interrelationships not only among the biotic community but also other physico-chemical parameters of the aquatic environment (Chakraborty 2013). Fish being a primarily adapted ectothermic aquatic faunal component fails to survive in the fluctuating temperature regimes which impose considerable eco-physiological stress on them disrupting normal metabolic pathways and result in subsequent mortality (Forghaly et al. 1973) experiencing considerable changes in the amount and proportion of different essential biochemical entities that are naturally occur in definite amount within them (Wilson and Taylor 1993). Besides, almost all biological parameters and processes within the framework of living organisms are critically dependent on environmental temperature, undesirable fluctuation of which pose serious threats to the life of all poikilothermal animals including fishes. These temperature mediated thermal stress may become effective independently or synergistically with those of other ecological parameters such as **pH**, dissolved oxygen, salinity, and species composition of associated biotic assemblages in natural water bodies (Wagner et al. 1997; Chakraborty 2013, 2017) and even in artificial aquatic systems (Barton and Schreck 1987; Donaldson 1990; Pearson et al. 1999).

In order to have an effective quantitative assessment of compensatory or adaptive changes in animals (changes of biochemical parameters in response of thermal stress), different methods in respect of acclimatization (pertaining to natural fluctuations of environmental variable) and acclimation (with a single laboratory-controlled variable) as outlined by Cossins and Bowler 1987 were adopted in the study conducted by Das et al. 2009 with two Indian major carps, *Labeo rohita and Cirrhinus mrigala*. In order to maintain physiological homeostasis during unfavorable temperature regime, teleosts can adopt both behavioral and physiological adaptabilities to overcome the stressed condition (Hazel and Prosser 1974; Prosser and Heath 1991). Acclimatization being the reflection of a cumulative form of different adjustments which enable the fishes to overcome long-term ecological changes [thermal changes (Das et al. 2004, 2006); changes in the dissolved oxygen and salinity (Adeyemo et al. 2003)] of the aquatic ecosystem resulting into the alteration of hormones, metabolic pathways, enzymes, and behavior of fishes to regain homeostasis. These metabolic changes may be considered as an important measure for assessing the effect of environmental perturbation, especially temperature. The research outcomes of previous researches (Das et al. 2004, 2006) have revealed that the oxygen consumption rate in conjunction with an increase gluconeogenic and glycogenolytic pathways in *L. rohita* increases with increasing acclimatization of temperatures from **26°C** to **36 °C** in order to maintain the homeostasis of the species. The studies by Das et al. 2009 have unearthed some valuable information pertaining to effects of different levels of temperatures (**26°C**, **31°C, 33°C,** and **36 °C**) on biochemical variables namely, blood glucose, liver glycogen, ascorbic acids of kidney and brain and total lipid, free fatty acids, phospholipids, and triglycerides and cholesterol, in the liver tissue of *L. rohita and C. mrigala*. It was found that although blood glucose and plasma cortisol levels showed a significant trend of increase in contrast to the significantly decreasing trend of liver glycogen contents and ascorbic acid concentration in brain and kidney on experiencing increased acclimatized temperature in both of the experimental species (*L. rohita and C. mrigala)*. Besides, the values for total lipid, phospholipid, cholesterol, triglycerides, and free fatty acids decreased significantly with increasing of such temperatures in both the species. However, all of these lipid-based parameters were estimated in higher amount in the *L rohita* in comparison to *C. mrigala* irrespective of the different acclimatization profiles in respect of changing temperatures. Cholesterol level was remained unaffected with increasing acclimatization temperatures in *L. rohita* whereas in *C. mrigala* the levels of changes of cholesterol in tune with the changing temperatures depicted an irregular trend. The increasing plasma cortisol and glucose levels at higher temperature indicate an increase in the level of stress in both *L. rohita* and *C. mrigala*. The primary stress response in fishes is reflected by the sharp increase in the level of stress hormones, especially cortisol (Wendelaar Bonga 1997; Barton 2002). Increase in the blood glucose and cortisol have been considered as the physiological manifestation of temperature mediated stress on the fishes (Kindle and Whitmore 1986; Davis and Parker 1990; Pérez-Casanova et al. 2008) which in turn trigger the production and mobilization of energy reserves as an adaptive means for maintaining homeostasis (Ackerman et al. 2000) and also a suitable pathway for the simultaneous release of glucose by the livers of fishes (Wendelaar Bonga 1997). In such context, the increase in the blood glucose levels with increasing acclimatization temperatures can act as a compensatory mechanism to meet the increasing demand of the energy at higher temperatures (Barton and Schreck 1987; Vijayan and Moon 1994). The increase in the amount of cortisol, directly or indirectly, increases glycogen mobilization (Reid et al. 1992; Vijayan and Leatherland 1992; Vijayan et al. 1993) and also directly hamper the gluconeogenesis process in the fishes (Vijayan et al. 1994). Glycogenolysis during the juvenile periods and gluconeogenesis in the adult stages of fishes are responsible for the increase of sugar as the outcomes of the impacts imposed by the ongoing thermal (Kindle and Whitmore 1986) and physical stresses (Barton and Iwama 1991; Reubush and Heath 1996) on the fishes.

In such context, this study had established the facts that the increased blood glucose was increased and concentration hepatic glycogen was reduced in the experimental carp species (*L. rohita* and *C. mrigala*) in the increased regime of acclimatization temperatures, and these were resulted due to increased glycogenolysis and gluconeogenesis mediated and facilitated by the increased cortisol. This had also explained the cause of development of hyperglycemia in L. rohita which was supposed to be predominantly due to glycogenolysis. Besides, the magnitude of reduction in the glycogen level, energy demand, and utilization in *L. rohita* was more in comparison to *C. mrigala* at higher temperatures (Das et al. 2009). Among so many essential biochemical entities of life, Vitamin C, represents an important one due to its proven anti-oxidative property which acts as an immunomodulator in the fishes (Dabrowski 1990b, Manush 1995, Cruz de Menezes et al. 2006; Norouzitallab et al. 2008). The study conducted by Das et al. 2009 had reported that the ascorbic acid contents in the brain and kidney tissues of two species major carps (*L. rohita* and *C mrigala*) were decreased with the increasing acclimation temperatures as both of these teleosts do not possess an active L-gluconolactone oxidase, the terminal enzyme in the ascorbic acid synthesis pathway (Dabrowski 1990a). Moreover, modulation of the antioxidants and induction in the production of reactive oxygen species leading to generate lipid peroxidation (**LPO**) is triggered by the thermal stress in fishes (Flanagan et al. 1998; Guderley 2004; Manush 1995). This study has also postulated that the reduction in the ascorbic acid levels due to increasing acclimation temperature indicates increased oxidative stress on both the species of fishes which was found to be more in *L. rohita* with a higher magnitude of reduction in ascorbic acid level than that in *C. mrigala* (Das et al. 2009).

One of the major biochemical components of living organisms is lipid which remains stored within the body in different forms such as triacylglycerols and the constituent polysaturated and polyunsaturated fatty acids (Sheridan 1994; Das 2002). This very important biochemical component experiences different form of changes in different phases in life in response to different environmental stimuli by rapidly breaking down, resynthesis, and interconversion in (Chetty and Indira 1994). Out of different components of lipid substrates, free fatty acids rapidly get circulated among the tissues, in comparison to triacylglycerols and phospholipids which move very slowly in blood circulation (Weber and Zwingelstein 1995). Fishes as a representative fauna of poikilotherms experience perturbation in their membrane structure sustaining alteration in the lipid structure in response to temperature fluctuation (Hazel 1995). The amount of total lipid was considerably decreased in the study conducted by Das et al. (2009) with the increasing temperature stress which was thought to be due to the mobilization of lipid for energy utilization.

Phospholipids being the major constituent of membrane lipids, contribute in the formation of lipoproteins, increase fat mobilization and assist in the absorption of fat-soluble vitamins in the gastrointestinal tract (Das 2002). Phospholipid concentration in *L. rohita* was found to be decreased with increasing acclimation temperatures, but this trend was followed by *C. mrigala* where the amount of phospholipid initially registered a declining trend with the increasing temperature up to **33 °C** and then its total amount was increased and reached to its maximum values at **36 °C.** Such findings in *C. mrigala* was supposed to be due to the adaptation of various components of cellular membrane to offer, ensure, and preserve the physiological integrity of cells. The functional role of cholesterol in forming cellular membrane and also serving as a precursor for the synthesis of steroid hormone and bile acids are well established (Das 2002). The stimulates, the hydrolysis of cholesteryl esters after being stimulated by the adrenocorticotropic hormone (**ACTH**) provide necessary inputs to cholesterol for the production of hormone (Montgomery et al. 1980). The cholesterol level was found to register a decreasing trend in *C. mrigala* up to **33 °C** and then increased at **36** °C, which was recorded always lower in comparison to *L. rohita* (Das et al. 2009). Triglyceride being the main constituent of body fat is an ester derived from the fatty acids and glycerol and contributes for energy production through mobilization (Das et al. 2009). It is an established fact that modification of lipid components help the maintenance of proper membrane fluidity and permeability of the cell membrane for the efficient functioning of the nervous system (Roots 1965).

The present research study had highlighted the species-specific responses and variation of these biochemical variables in *L. rohita* and *C. mrigala* in response to increasing acclimation temperatures and differences recorded in two species were thought to be due to their different ecological niches within the same aquatic habitat. This study also points out that thermal acclimation should be considered as an essential physiological phenomenon in the life cycle of ectotherms relying strongly on the ambient temperature and such acclimation trigger elicits compensatory responses enabling the fishes to intrude, adapt and settle in the new ecological condition (Das et al. 2009).

3.27.8 Impact of Temperature Stress on the Organs of Indian Major Carps: An Histopathological Assessment at Ultrastructural Levels

Gills of ectothermic fishes and also in shellfishes play vital roles in undertaking different physiological functions such as respiration through gaseous exchange (Hughes 1982), acid-base balance (Lin and Randall 1991; Goss et al. 1992); osmoregulation (Verbost et al. 1994) and excretion of nitrogenous compounds (Evans and Cameron 1986; Sayer and Davenport 1987). Besides, gills major carp species of tropical aquatic bodies act as an effective organ for indicating thermal pollution (Alazemi et al. 1996) and also other categories of aquatic pollution (Lichtenfels et al. 1996; Pawert et al. 1998) as these organs remain in intimate association with the surrounding aquatic environment for maintaining the thermal equilibrium between the environment and fish body as the heat exchangers by bathing in the inflow of oxygenated and outflow of deoxygenated water acting as a site for the exchange of gases during respiration of the fishes (Stevens and Sutterlin 1976).

An experimental study undertaken with one of the major tropical carp species (Teleost: *Labeo rohita*) inhabiting in the freshwater ecosystems of India to observe the morpho-anatomical alterations, even at ultrastructural levels because of the exposure of the experimental subject species against extreme temperature regime have shown that they suffer respiratory stress and nerve disorders because of the dual effect of the enhanced temperature on their oxygen demand/supply ratio as the warmer waters carry less dissolved oxygen, whereas the demands of this aquatic organism for the uptake of oxygen is increased due to their high metabolic rate.

This fish having been acclimated to ambient temperature (**26 °C**) possess normal ultrastructures of the gills, indicating normal healthy conditions (Jhingran 1975) also experience the alteration of morphology of their prime respiratory organs. This study has also shown the appearance of increased vacuolated space in the gill tissue of fish exposed to higher temperature which was thought to be due to the development of osmotic imbalance as higher water temperature tend to alter the lipids in the gill cells, causing leakages coupled with the reduction in the efficiency of salt excretion and balance (Munro 2001).

In addition, this study also pointed out the occurrences of mitochondrial hypertrophy and hyperplasia as a sequel of the compensatory mechanism in the experimental species (*L. rohita*) which tried more to derive energy to combat the temperature stress. The appearance of increased mitochondrial density exposed to temperature stress could also be ascertained as an adaptive response to the thermal stress. Besides, this study has also indicated that the alteration of cellular integrity in the gills was due to the exposure to thermal extremes, Considering all, these research findings can be used effectively in developing proper aquatic bioresource management strategies especially in the era of global warming (Das et al. 2014).

3.27.9 Concluding Remarks on the Impact of Global Warming on the Fishery and Aquacultural Progress in India

India, as one of the biggest producers of the freshwater fishes in the world after China (FAO 2001), has intensified and increased the production of Indian Major Carps (*Labeo rohita*, *Catla catla,* and *Cirrhinus mrigala*) by adopting the selective breeding and hybridization (Chaudhuri 1971). Global warming mediated increased temperature one of the major ecological parameters (Gadomski and Caddell 1991) have influenced considerably the hatching percentage and survival of embryos and larvae. Proper understanding on the influence and effect of temperature on the embryological and morpho anatomical development, hatching, and rates are thought to be useful for commercial fish propagation in the varied climatic conditions in India.

Global warming mediated climate change should not only be considered as a process for increasing normal temperature ranges in the atmosphere causing melting of the polar caps and thereby rising of sea level. Instead, it involves a chain of reactions jeopardizing the basic fabric of ecosystem functioning, especially in the aquatic systems by increasing the frequency of hydro-geo-biochemical-physical-meteorological events. Temperature being the prime physical factor determines the distribution, abundance, and survival of species. Aquatic fauna has acquired effective thermal adaptation by virtue of possessing and activating some biochemical components such as Heat Shock Proteins (**HSPs**) and also by triggering the expression of heat shock genes which tend to reduce the expression of "**housekeeping**" genes. During on exposing to a continued exposure of elevated temperature but within tolerable range, cells initially withstand, adapt, and return to a state of almost normal form of gene expression, representing a state called "**General Adaptation Syndrome**" which in turn enable the cells to retain and maintain natural homeostasis under different adverse conditions (Chakraborty et al. 2014).

References

Aarts, B.G.W., and P.H. Nienhuis. 2003. Fish zonations and guilds as the basis for assessment of ecological integrity of large rivers. *Hydrobiologia* 500: 157–178.

Aarts, B.G.W., F.W.B. Van Den Brink, and P.H. Nienhuis. 2004. Habitat loss as the main cause of the slow recovery of fish faunas of regulated large rivers in Europe: The transversal floodplain gradient. *River Research and Applications* 20: 3–23.

Ackerman, P.A., R.B. Forsyth, C.F. Mazur, and G.K. Iwama. 2000. Stress hormones and the cellular stress response in salmonids. *Fish Physiology and Biochemistry* 23: 327–336.

Adeyemo, O.K., S.A. Agbede, A.O. Olaniyan, and O.A. Shoaga. 2003. The haematological response of *Clarias gariepinus* to changes in acclimation temperature. *African Journal of Biomedical Research* 6: 105–108.

Akin-Oriola, G.A., M.A. Anetekhai, and A. Oriola. 2006. Algal bloom in Nigerian waters: an overview. *African Journal of Marine Science* 28 (2): 219–224.

Alazemi, B.M., J.W. Lewis, and E.B. Andrews. 1996. Gill damage in freshwater fish *Gnthonemus ptersii* (family: Mormyridae) exposed to selected pollutants: An ultrastructure study. *Environmental Technology* 17: 225–238.

Allan, J.D. 1995. Stream ecology. Structure and function of running waters. Chapman & Hall, London, 388 pp.

Allen, K.R. 1969. Distinctive aspects of the ecology of stream fishes: A review. *Journal of the Fisheries Research Board of Canada* 26: 1429–1438.

Allan, J.D. 1975a. The distribution ecology and diversity of benthic insects in Cement Creek, Colorado. *Ecology* 56: 1040–1053.

———. 1975b. Faunal replacement and longitudinal zonation in an alpine stream. *Verhandlungen des Internationalen Verein Limnologie* 19: 1646–1652.

———. 1982. The effects of reduction in trout density on the invertebrate community of a mountain stream. *Ecology* 63: 1444–1455.

———. 1995. *Stream ecology: Structure and function of running water*. New York: Chapman & Hall.

Allan, J.D., and A.S. Flecker. 1993. Biodiversity conservation in running waters. *Bioscience* 43: 32–43.

Angermeier, P.L., and J.R. Karr. 1984. Relationships between woody debris and fish habitat in a small warmwater stream. *Transactions of the American Fisheries Society* 113: 716–726.

Amoros, C., and G. Bornette. 2002. Connectivity and biocomplexity in waterbodies of riverine floodplains. *Freshwater Biology* 47: 761–776.

Amoros, C., and A.L. Roux. 1988. Interaction between water bodies within the floodplain of large rivers: Function and development of connectivity. *Münstersche Geographische Arbeiten* 29: 125–130.

Anand, S.S., S. Sardessai, C. Muthukumar, K.R. Mangalaa, D. Sundar, S.G. Parab, and M.D. Kumar. 2014. Intra and inter seasonal variability of nutrients in a tropical monsoonal estuary (Zuari, India). *Continental Shelf Research* 82: 9–30.

Anon, 2002. Inventory of threatened fresh water fishes of Midnapore District with an emphasis on bioecological studies of selected carp fishes for conservation and propagation (Sanctioned by the D.S.T., Government of West Bengal, India. Sanction No. 410/ST/P/S & T/1G-4/99, dated, 29.02.2000. Principal Investigator: S.K. Chakraborty).

Archer, D., and S. Rahmsterf. 2010. *The climate crisis- an introductory guide to climate change*, 1–248. Cambridge University Press.

Atkinson, D. 1996. Ectotherm life-history responses to developmental temperature. In *Animals and temperature. Phenotypic and evolutionary adaptation*, ed. I.A. Johnston and A.F. Bennett, 183–204. Cambridge: Cambridge University Press.

Baker, S.C., and R.C. Heidinger. 1996. Upper lethal temperature of fingerling black crappie. *Journal of Fish Biology* 48: 1123–1129.

Baird, A.J., L.R. Belyea, and P.J. Morris. 2009. Upscaling of peatland-atmosphere fluxes of methane: Small-scale heterogeneity in process rates and the pitfalls of “bucket-and-slab” models. In *Geophysical monograph series*, ed. A.J. Baird, L.R. Belyea, X. Comas, A.S. Reeve, and L.D. Slater, 37–53. Washington: American Geophysical Union.

Barbour, M.T., J. Gerritsen, B. Snyder, and J. Stribling. 1999. Rapid bioassessment protocols for use in streams and Wadeable Rivers. *USEPA, Washington Bdhle* 1978.

Barton, B.A. 2002. Stress in fishes: A diversity of responses with particular reference to changes in circulating corticosteroids. *Integrative and Comparative Biology* 42: 517–525.

Barton, B.A., and G.K. Iwama. 1991. Physiological changes in fish from stress in aquaculture with emphasis on the response and effects of corticosteroids. *Annual Review of Fish Diseases* 1: 3–26.

Barton, B.A., and C.B. Schreck. 1987. Metabolic cost of acute physical stress in juvenile steelhead. *Transactions of the American Fisheries Society* 116: 257–263.

Becker, C.D. 1990. *Aquatic bioenvironmental studies: The Handford experience, 1944–1984*, Studies in Environmental Science 39. Amsterdam: Elsevier.

Becker, C.D., and R.H. Gray. 1992. Past and present water quality conditions in the Hanford reach, Columbia River. *Environ Monit Assess* 22: 137–152.

Beitinger, T.L., W.A. Bennett, and R.W. McCauley. 2000. Temperature tolerances of north American freshwater fishes exposed to dynamic changes in temperature. *Environmental Biology of Fishes* 58: 237–275.

Beisel, J.N., P. Usseglio-Polatera, V. Bachmann, and J.C. Moreteau. 2003. A comparative analysis of evenness index sensitivity. *International Review of Hydrobiology* 88: 3–15.

Belpaire, C., R. Smolders, I.V. Auweele, D. Ercken, J. Breine, G. Van Thuyne, and F. Ollevier. 2000. An index of biotic integrity characterizing fish populations and the ecological quality of Flandrian water bodies. *Hydrobiologia* 434: 17–33.

Benton, T.G., D.M. Bryant, L. Cole, and H.P.Q. Crick. 2002. Linking agricultural practice to insect and bird populations: A historical study over three decades. *Journal of Applied Ecology* 39: 673–687.

Berkman, H.E., and C.F. Rabeni. 1987. Effect of siltation on stream fish communities. *Environmental Biology of Fishes* 18: 285–294.

Bevelhimer, M., and W. Bennett. 2000. Assessing cumulative thermal stress in fish during chronic intermittent exposure to high temperatures. *Environmental Science & Policy* 3: S211–S216.

Biggs, J., A. Corfield, P. Grøn, H.O. Hansen, D. Walker, M. Whitfield, and P. Williams. 1998. Restoration of the rivers Brede, Cole and Skerne: A joint Danish and British EU-LIFE demonstration project. V. Short-term impacts on the conservation value of aquatic macroinvertebrate and macrophyte assemblages. *Aquatic Conservation: Marine and Freshwater Ecosystems* 8: 241–255.

Blaxter, J.H.S. 1981. The rearing of larval fish. In *Aquarium systems*, ed. A.D. Hawkins, 303–323. London: Academic.

Bonetto, A.A., E. Cordiviola de Yuan, C. Pignalberi, and O. Oliveros. 1970. Nuevos datos sobre poblaciones de peces en ambientes permanentes del Paraná Medio. *Physis* 30: 141–154.

Bonetto, A.A., J.J. Neiff, and D.H. Di Persia. 1986. The Parana river system. In *The ecology of river system*, 541–598.

Bowen, S.H. 1983. Detritivory in neotropical fish communities. *Environmental Biology of Fishes* 9: 137–144.

Bowen, J.D. 2000. Calibration performance of a two dimensional, laterally -averaged eutrophication model of a partially mixed estuary. In *Estuarine and coastal modeling: Proceeding of 6th International Conference*, ed. M.L. Spaulding and A.F. Blumberg, 1244–1258. New York: ASCE.

Bozzetti, M., and U.H. Schulz. 2004. An index of biotic integrity based on fish assemblages for subtropical streams in southern Brazil. *Hydrobiologia* 529: 133–144.

———. 2003. Effects of flow regulation on shallow-water habitat dynamics and floodplain connectivity. *Transactions of the American Fisheries Society* 132: 809–823.

Bowen, Z.H., K.D. Bovee, and T.J. Waddle. 1984. Evidence of a detritus food chain based on consumption of organic precipitates. *Bulletin of Marine Science* 35: 440–448.

Bratton, S.P. 1975. The effect of the European wild boar Sus scrofa, on gray beech forest in the Great Smoky Mountains. *Ecology* 56: 1356–1366.

Brett, J.R. 1964. The respiratory metabolism and swimming performance of young sockeye salmon. *Journal of the Fisheries Research Board of Canada* 21: 1183–1226.

———. 1970. Temperature—Fishes. In *Marine ecology*, Environmental factors, part 1, ed. O. Kinne, vol. I, 515–560. London: Willey-Interscience.

———. 1979. Environmental factors and growth. In *Fish physiology*, ed. W.S. Hoar, D.J. Randall, and J.R. Brett, vol. VIII, 599–675. London: Academic.

Briand, C., B. Sauvaget, P. Girard, D. Fatin, and L. Beaulaton. 2012. Push net fishing seems to be responsible for injuries and post fishing mortality in glass eel in the Vilaine estuary (France) in 2007. *Knowledge Management in Aquaculture Ec* 404: 02.

Brookes, A. 1985. River channelisation: Traditional engineering methods, physical consequences and alternative practices. *Progress in Physical Geography* 9: 44–73.

———. 1992. Recovery and restoration of some engineered British river channels. In *River conservation and management*, ed. P.J. Boon, P. Calow, and G.E. Petts, 337–352. Chichester: Wiley.

Brooks, J.L., and S.L. Dodson. 1965. Predation, body size and composition of plankton. *Science* 150: 28–35.

Burel, C., P.L. Ruyet, F. Gaumet, A.L. Roux, A. Severe, and G. Boeuf. 1996. Effectsof temperature on growth and metabolism in juvenile turbot. *Journal of Fish Biology* 49: 678–692.

Butchart, S.H., J.P. Scharlemann, M.I. Evans, S. Quader, S. Aricò, J. Arinaitwe, et al. 2012. Protecting important sites for biodiversity contributes to meeting global conservation targets. *PLoS One* 7: e32529. https://doi.org/10.1371/journal.pone.0032529.

Caldecott, J. 1996. *Designing conservation projects*, 1–312. Cambridge: Cambridge University Press.

Cao, and S. Ikeda. 2005. Inter-zonal tradable discharge permit system to control water pollution in Tianjin, China. *Environmental Science & Technology* 399 (13): 4692–4699.

Carignan, V., and V. Marc-Andre. 2002. Selecting indicator species to monitor ecological integrity: A review. *Environmental Monitoring and Assessment* 78 (1): 45–61.

———. 2004. *Biological indicators in environmental monitoring programs: Can we increase their effectiveness ?* CRC Press LLC.

Carpenter, S.R., S.G. Fisher, N.B. Grimm, and J.F. Kitchell. 1992. Global change and freshwater ecosystems. *Annual Review of Ecology and Systematics* 23: 119–139.

Carpenter, S.R., and J.F. Kitchell. 1988. Consumer control of lake productivity. *Bio- Science* 38: 764–769.

Casatti, L., C.P. Ferreira, and F. Langeani. 2009. A fish-based biotic integrity index for assessment of lowland streams in southeastern Brazil. *Hydrobiologia* 623: 173–189.

Cassner, H., G. Tischler, and J. Wanzenbock. 2003. Ecological integrity assessment of lakes using fish communities suggestions of new metrics developed in two Austrian Prealpine Lakes. *International Review of Hydrobiology* 88 (6): 635–652.

CBD. 2010. *The convention on biological diversity*. United Nations Environment Programme.

Cetra, M., and M. Petrete Jr. 2006. Fish assemblage structure of the Corumbatai river basin, Sao Paulo State, Brazil: Characterization and anthropogenic disturbances. *Brazillian Journal of Biology* 66 (2A): 431–439.

Chakraborty, S.K. 2003. Biodiversity and conservation. In *Perspectives and issues in environmental studies*, ed. A.D. Mukhopadhyay, 267–286. Medinipur: Vidyasagar University.

———. 2017. Ecological services on intertidal benthic fauna and the sustenance of coastal wetlands along the Midnapore (East) coast, West Bengal, India (Published in the book, Coastal Wetlands: Alteration and Remediation, Springer), 777–886.

———.2018. Bioinvasion and environmental perturbation : Synergistic impact on coastal – mangrove ecosystems of West Bengal, India (Published in the book, Impacts of invasive species on coastal environments: Coast in crisis; edited by Makowski, C and Finkl, C and published by Springer), 171–245.

Chakraborty, S.K. 2013. Interactions of environmental variables determining the biodiversity of coastal mangrove ecosystem of West Bengal, India. *The Ecoscan. Special Issue* 3: 251–265.

Chakraborty, S.K., S. Maiti Dutta, P.B. Ghosh, R. Ray, and A.K. Paul. 2014. Impact of global warming on Sundarbans mangrove ecosystem, India: Role of different assessment tools from ecosystem monitoring to molecular markers. In *Proceedings of the International conference on Green India: Strategic knowledge for combating climate change: Prospects and Challenges*, 181–200.

———. 2017. Ecological services on intertidal benthic fauna and the sustenance of coastal wetlands along the Midnapore(East) coast, West Bengal, India. In *Coastal wetlands: Alteration and remediation*, 777–886. Springer.

———. 2018. Bioinvasion and environmental perturbation: Synergistic impact on coastal – Mangrove ecosystems of West Bengal, India. In *Impacts of invasive species on coastal environments: Coast in crisis*, ed. C. Makowski and C. Finkl, 171–245. Springer.

Chapman, D.W., and E. Knudsen. 1980. Channelization and livestock impacts on salmonid habitat and biomass in western Washington. *Transactions of the American Fisheries Society* 109: 357–363.

Chatterjee, N., A.K. Pal, S.M. Manush, T. Das, and S.C. Mukherjee. 2004. Thermal tolerance and oxygen consumption of Labeo rohita and Cyprinus carpio early fingerlings acclimated to three different temperatures. *Journal of Thermal Biology* 29: 265–270.

Chaudhuri, H. 1971. *Fish hybridization in Asia with special reference to India*, Lecture. Rep. Vol. 2926, 133–142. UNDP, FAO.

Cheng, G., Li Xin, W. Zhao, Z. Xu, Q. Feng, S. Xiao, and H. Xiao. 2014. *Natural Science Review* 1: 413–428.

Chetty, A.N., and K. Indira. 1994. Alterations in tissue lipid profiles of *Lamellidens marginalis* under ambient ammonia stress. *Bulletin of Environmental Contamination and Toxicology* 55: 693–698.

Christensen, J.H., B. Hewitson, A. Busuioc, A. Chen, X. Gao, I. Held, R. Jones, R.K. Kolli, W.T. Kwon, R. Laprise, V. Magaña Rueda, L. Mearns, C.G. Menéndez, J. Räisänen, A. Rinke, A. Sarr, and P. Whetton. 2007. Regional climate projections. In *2007 Climate change: The physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, ed. S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor, and H.L. Miller. Cambridge/New York: Cambridge University Press.

Chung, M.K., J.H. Choi, Y.K. Chung, and K.M. Chee. 2005. Effects of dietary vitamins C and e on eggshell quality of broiler breeder hens exposed to heat stress. *Asian-Australasian Journal of Animal Sciences* 18 (4): 545–551.

Cody, M.L. 1975. Towards a theory of continental species diversity: bird distributions over Mediterranean habitat gradients. In *Ecology and evolution of communities*, ed. M.L. Cody and J.M. Diamond, 214–257. Cambridge: Harvard University Press.

Cohen, J.E., T. Jonsson, and S.R. Carpenter. 2003. Ecological community description using the food web, species abundance, and body size. *Proceedings of the National Academy of Sciences* 100 (4): 1781–1786.

Cole, G.A. 1983. *Textbook of limnology*. 3rd ed, 1–401. London: The C.V. Mosby Company.

Cook, R.E. 1977. Raymond Lindeman and the trophic dynamic concept in ecology. *Science* 198: 22–26.

Cooper, A.A., Yin-Phan Tsang, D.M. Infante, W.M. Danie, A.J. McKerrow, and D. Wieferich. 2019. Protected areas lacking for many common fluvial fishes of the conterminous USA. *Diversity and Distribution* 25: 1289–1303.

Cossins, A.R., and K. Bowler. 1987. *Temperature biology of animals*. London: Chapman and Hall.

Copp, G.H. 1997. Microhabitat use of fish larvae and 0+ juveniles in a highly regulated section of the River Great Ouse. *Regulated Rivers: Research and Management* 13: 267–276.

Cowx, I.G., and R.L. Welcomme. 1998. *Rehabilitation of Rivers for fish*. Oxford: Fishing News Books.

Cowx, I.G., G.A. Wheatley, and A.S. Mosley. 1986. Long-term effects of land drainage works on fish stocks in the upper reaches of a lowland river. *Journal of Environmental Management* 22: 147–156.

Crook, D.A., A.I. Robertson, A.J. King, and P. Humphries. 2001. The influence of spatial scale and habitat arrangement on diel patterns of habitat use by two lowland river fishes. *Oecologia* 129: 525–533.

Cruz de Menezes, G., M. Tavares-Dias, E.A. Ono, J.I. Alves de Andrade, E.M. Brasil, R. Roubach, E.C. Urbinati, J.L. Marcon, and E.G. Afoonso. 2006. The influence of dietary vitamin C and E supplementation on the physiological response of pirarucu, *Arapaima gigas* in net culture. *Comparative Biochemistry and Physiology A* 145: 274–279.

Culp, J.M., and R.W. Davies. 1980. Reciprocal averaging and polar ordination as techniques for analyzing lotic macroinvertebrate communities. *Canadian Journal of Fisheries and Aquatic Sciences* 37: 1358–1364.

Culp, J.M., G.J. Scrimgeour, and G.D. Townsend. 1996. Simulated fine woody debris accumulations in a stream increase rainbow trout fry abundance. *Transactions of the American Fisheries Society* 125: 472–479.

Cui, Y., and R.J. Wootton. 1988. Effectsof ration, temperature and body size on the body composition and energy content of the minnow, Phoxinus phoxinus (L.). *Journal of Fish Biology* 32: 749–764.

Currie, S., C.D. Moyes, and B.L. Tufts. 2000. The effects of heat shock and acclimation temperature on HSP70 and HSP30 mRNA expression in rainbow trout: *in vivo* and *in vitro* comparisons. *Journal of Fish Biology* 56: 398–408.

Dabrowski, K. 1990a. Gulonolactone oxidase is missing in teleost fish – A direct spectrophotometric assay. *Biological Chemistry Hoppe-Seyler* 371: 207–214.

———. 1990b. Ascorbic acid status in the early life of whitefish (*Coregonus ivaretus*, L). *Aquaculture* 84: 61–70.

Das, D. 2002. Metabolism of lipids. In *Biochemistry*, ed. D. Das, 505–566. Kolkata: Academic.

Das, T., A.K. Pal, S.K. Chakraborty, S.M. Manush, N. Chatterjee, and S.C. Mukherjee. 2004. Thermal tolerance and oxygen consumption of Indian Major Carps acclimated to four temperatures. *Journal of Thermal Biology* 23: 157–163.

Das, T., A.K. Pal, S.K. Chakraborty, S.M. Manush, N.P. Sahu, and S.C. Mukherjee. 2005. Thermal tolerance, growth and oxygen consumption of Labeo rohita fry (Hamilton, 1822) acclimated to four temperatures. *Journal of Thermal Biology* 30: 378–383.

Das, T., A.K. Pal, S.K. Chakraborty, S.M. Manush, R.S. Dalvi, K. Sarma, and S.C. Mukherjee. 2006a. Thermal dependence of embryonic development and hatching rate in Labeo rohita (Hamilton, 1822). *Aquaculture* 255: 536–541.

Das, T., A.K. Pal, S.K. Chakraborty, S.M. Manush, and N. Chatterjee. 2006b. Metabolic elasticity and induction of heat shock protein 70 in *Labeo rohita* acclimated to three temperatures. *Asian-Australasian Journal of Animal Sciences* 19: 1033–1039.

Das, T., A.K. Pal, S.K. Chakraborty, S.M. Manush, R.S. Dalvi, S.K. Apte, N.P. Sahu, and K. Baruah. 2009. Biochemical and stress responses of rohu *Labeo rohita* and mrigal *Cirrhinus mrigala* in relation to acclimation temperatures. *Journal of Fish Biology* 74: 1487–1498.

Das, T., N.P. Sahu, S.K. Chakraborty, N. Chatterjee, M.S. Mohammed, R.S. Dalvi, K. Baruah, and A.K. Pal. 2014. Ultrastructural alterations in the gills of Labeo rohita fingerlings exposed to thermal extremes. *Anatomia Histologia Embryologia* 43 (2014): 75–80.

Dauwalter, D.C., and J. Jackson. 2004. A provisional fish index of biotic integrity for assessing Ouachita Mountains streams in Arksnsas, USA. *Environmental Monitoring and Assessment* 91 (1–3): 27–57.

Dauwalter, D.C., E.J. Pert, and W.E. Keith. 2003. An index of biotic integrity for fish assemblages in Ozark Highland streams of Arkansas. *Southeastern Naturalist* 2 (3): 447–468.

Davis, B.K., and N.C. Parker. 1990. Physiological stress in striped bass: Effect of acclimation temperature. *Aquaculture* 91: 349–358.

Day, F. 1875–78. The Fishes of India ; being a natural history of the fishes known to inhabit the seas and fresh waters of India, Burma and Ceylon. Text and atlas in 4 parts. London, xx +778.

———. 1889. *The fauna of British India: Fishes*. London: Taylor and Francis.

De Eyto, E., and K. Irvine. 2007. Assessing the status of shallow lakes using an additive model of biomass size spectra. *Aquatic Conservation,: Marine and Freshwater Ecosystem* 17: 724–736.

De Graaf, G. 2003. Dynamics of floodplain fisheries on Bangladesh, results of 8 years fisheries monitoring in the compartmentalization Pilot Project. *Fish Management Ecology* 10: 191–199.

Degerman, E., J. Hammar, P. Nyberg, and G. Svardson. 2002. Human impact on the fish diversity in the four largest lakes of Sweden. *Ambio* 30 (8): 522–528.

Dodson, J.J. 1997. Fish migration: An evolutionary perspective. In *Behavioral ecology of teleost fishes*, ed. J.G. Godin, 10–36. Oxford: Oxford University Press.

Domenech, L., H. March, and D. Sauri. 2013. Contesting large -scale water supply projects at both ends of the pipe in Kathmandu and Melamchi Valleys, Nepal. *Geoforum* 47: 22–31.

Diamond, J.M. 1972. Biogeographic kinetics: Estimation of relaxation times for avifaunas of Southwest Pacific Islands. *Proceedings of the National Academy of Sciences of the USA* 69: 3199–3203.

Dietz, T.J., and G.N. Somero. 1992. The threshold induction temperature of the 90 kDa heat shock protein is subject to acclimatization in eurythermal goby fishes (Gillichhys). *Proceedings of National Academy of Science USA* 89: 3389–3339.

Donaldson, E.M. 1990. Reproductive indices as measures of the effects of environmental stressors in fish. *American Fisheries Society Symposium* 8: 109–122.

Dudgeon, D. 2000. The ecology of tropical Asian rivers and streams in relation to biodiversity conservation. *Annual Review ofEcology and Systematics* 31: 239–263.

Dynesius, M., and C. Nilsson. 1994. Fragmentation and flow regulation of the river systems in the northern third of the world. *Science* 266: 753–762.

Edwards, C.J., B.L. Griswold, R.A. Tubb, E.C. Weber, and L.C. Woods. 1984. Mitigating effects of artificial riffles and pools on the fauna of a channelized warm water stream. *North American Journal of Fisheries Management* 4: 194–203.

Egerton, F.N. 1985. *Overfishing or pollution ? Case history of a controversy on the Great Lakes*. Ann Arbor: Great Lakes Fishery Commission.

Egerton, F.N. 2015. *A centennial history of the Ecological Society of America*. Boca Raton: CRC press / Taylor and Francis.

Egginnton, S., and B.D. Sidell. 1989. Thermal acclimation induces changes in subcellular structure of fish skeletal muscle. *American Journal of Physiology* 256: R1–R9.

Ehlinger, T.J. 1990. Habitat choice and phenotype -limited feeding efficiency in bluegill: Individual differences and trophic polymorphism. *Ecology* 71: 886–896.

Ellegren, H., and B.C. Sheldon. 2008. Genetic basis of fitness differences in wild populations. *Nature* 452: 169–175.

Elliott, J.M. 1981. Some aspects of thermal stress on freshwater teleosts. In *Stress and fish*, ed. A.D. Pickering, 209–245. London: Academic.

Elton, C.S. 1927. *Animal ecology*. London: Sidgwick and Jackson.

Evans, D.H., and J.N. Cameron. 1986. Gill ammonia transport. *The Journal of Experimental Zoology* 239: 17–23.

FAO. 2001. *Year book on fishery statistics*. Italy: Rome.

———. 2006. *The state of world fisheries and aquaculture*. Rome: FAO, 162 pp. 88 Climate change implications for fisheries and aquaculture – Overview of current scientific knowledge.

Ferreira, C.P., and L. Casatti. 2006. Influência da estrutura do habitat sobre a ictiofauna de um riacho em uma micro-bacia de pastagem, São Paulo, Brasil. *Revista Brasileira de Zoologia* 23: 642–651.

Feder, M.E., and G.E. Hofmann. 1999. Heat shock proteins, molecular chaperons, and the stress response: Evolutionary and ecological physiology. *Annual Review of Physiology* 61: 243–282.

Feige, U., R. Morimoto, I. Yahara, and B.S. Polla. 1996. *Stressinducible cellular responses*, 1–492. Basel: Birkhauser-Verlag.

Flanagan, S.W., P.L. Moseley, and G.R. Buettner. 1998. Increased flux of free radicals in cells subjected to hyperthermia: Detection by electron paramagnetic resonance spin trapping. *FEBS Letters* 431: 285–286.

Flecker, A.S., and C.R. Townsend. 1994. Community-wide consequences of trout introduction in New Zealand streams. *Ecological Applications* 4: 798–807.

Flöder, S., and C.W. Burns. 2004. Phytoplankton diversity of shallow tidal lakes: Influence of periodic salinity changes on diversity and species number of a natural assemblage. *Journal of Phycology* 40: 54–61.

Forghaly, A.M., A.A. Ezzat, and M.B. Shabana. 1973. Effect of temperature and salinity changes on the blood characteristics of Tilapia zilli in Egyptian littoral lakes. *Comparative Biochemistry and Physiology A* 46: 183–193.

Forsyth, R.B., E.P.M. Candido, S.L. Babich, and G.K. Iwama. 1997. Stress protein expression in Coho salmon with bacterial kidney disease. *Journal of Aquatic Animal Health* 9: 18–25.

Foufopoulos, J., and A.R. Ives. 1999. Reptile extinction on land-bridge islands: Life-history attributes and vulnerability to extinction. *American Naturalist* 153: 1–25.

Frazier, P., and K. Page. 2009. A reach-scale remote sensing technique to relate wetland inundation to river flow. *River Research and Applications* 25: 836–849. https://doi.org/10.1002/rra.1183.

Frey, D.G., ed. 1963. *Limnology in North America*. Madison: University of Wisconsin Press.

Frey, K.E., and J.W. McClelland. 2009. Impacts of permafrost degradation on arctic river biogeochemistry. *Hydrological Processes* 23: 169–182. https://doi.org/10.1002/hyp.7196.

Frissel, C.A., W.J. Liss, C.E. Warren, and M.D. Hurley. 1986. A hierarchical framework for stream habitat classification: Viewing streams in a watershed context. *Environmental Management* 10: 199–214.

Flecker, A.S. 1996. Ecosystem engineering by a dominant detritivore in a diverse tropical stream. *Ecology* 77: 1845–1854.

Fuchs, U., and B. Statzner. 1990. Time scales for the recovery potential of river communities after restoration, lessons to be learned from smaller streams. *Regulated Rivers: Research and Management* 5: 77–87.

Fukushima, T., T. Ishibashi, and A. Imai. 2001. Chemical characterization of dissolved organic matter in Hiroshima Bay, Japan. *Estuarine Coastal and Shelf Science* 53: 51–62.

Gadomski, D.M., and S.M. Caddell. 1991. Effects of temperature on early life history stages of California halibut, Paralichthys californicus. *Fisheries Bulletin U. S.* 89: 567–576.

Giller, P.S., and A.A. Myers. 1996. *Disturbance and recovery in ecological systems*. Dublin: Royal Irish Academy.

Gilliam, J.F., D.F. Fraser, and M. Alkins-Koo. 1993. Structure of a tropical stream fish community: A role for biotic interactions. *Ecology* 74: 1856–1870.

Giri, S., and S.K. Chakraborty. 2012. Assessment of fishery resources in relation to some physico-chemical parameters of water in Sundarbans mangrove ecosystem, India. *Advances in Applied Research* 3 (4): 2337–2345.
Glasby, G., and B and Roonwal, G.S. 1995. Marine pollution in India: An emergent problem. *Current Science* 5: 495–498.
Gleick, P.H. 1998. *The world's water 1998–1999: The bi- ennial report on freshwater resources*. Washington, D.C.: Island Press.
Goodwin, R.A., M. Politano, J.W. Garvin, and J.M. Nestler. 2014. Fish navigation of large dams emerges from their modulation of flow field experience. *Proceedings of the National Academy of Sciences* 111 (14): 1–6.
Gorman, O., and J.R. Karr. 1978. Habitat structure and stream fish communities. *Ecology* 59 (3): 507–515.
Goss, G.G., S.F. Perry, C.M. Wood, and P. Laurnet. 1992. Mechanism of ion and acid base regulation at the gills of freshwater fish. *The Journal of Experimental Zoology* 263: 143–159.
Gould, S.J. 1977. *Ontogeny and phylogeny*. Cambridge, MA: The Belknap Press of Harvard University Press.
Goulding, M., M.L. Carvalho, and E.G. Ferreira. 1988. *Rı'o Negro: Rich life in poor water*. The Hague: SPB Academic Publishing.
Grift, R.E., A.D. Buijse, G.P. KleinBreteler, W.L.T. van Densen, M. Machiels, and J.J.G.M. Backx. 2001. Migration of bream between the main channel and floodplain lakes along the lower river Rhine during the connection phase. *Journal of Fish Biology* 59: 1033–1055.
Grinnell, J. 1917. The niche-relationships of the California thrasher. *Auk* 34: 427–433.
Guderley, H. 2004. Metabolic responses to low temperature in fish muscle. *Biological Reviews of the Cambridge Philosophical Society* 79: 409–427.
Gupta, A., D.K. Rai, R.S. Pandey, and B. Sharma. 2008. Analysis of some heavy metals in the riverine water, sediments and fish from the Ganges at Allahabad. *Environmental Monitoring and Assessment* 157 (1–4): 449–458.
Gutreuter, S., A.D. Bartels, K. Irons, and M.B. Sandheinrich. 1999. Evaluation of the flood-pulse concept based on statistical models of growth of selected fishes of the upper Mississippi River system. *Canadian Journal of Fisheries and Aquatic Sciences* 56: 2282–2291.
Hall, B.K. 1922. *Evolutionary developmental biology*. London: Chapman and Hall.
Halpern, B.S., S. Walbridge, K.A. Selkoe, C.V. Kappel, F. Micheli, C. D'Agrosa, J.F. Bruno, K.S. Casey, C. Ebert, H.E. Fox, R. Fujita, D. Heinemann, H.S. Lenihan, E.M.P. Madin, M.T. Perry, E.R. Zelig, M. Spalding, R. Steneck, and R. Watson. 2008. A global map of human impact on marine ecosystems. *Science* 319: 948–952.
Haidvogl, G., D. Lajus, D. Pont, and M. Schmid. 2014. Typology of historical sources and the reconstruction of long-term historical changes of riverine fish: A case study of the Austrian Danube and northern Russian rivers. *Ecology of Freshwater Fish* 23 (4): 498–515.
Haraldsen, T.K., and P. Stalnacke. 2006. Methods for water quality sampling and load estimation in monitoring of Norwegian agricultural catchments. *Nordic Hydrology* 37: 81–92.
Harley, C.D.G., R.A. Hughes, K.M. Hultgren, B.G. Miner, C.J.B. Sorte, C.S. Thornber, L.F. Rodriguez, L. Tomanek, and S.L. Williams. 2006. The impacts of climate change in coastal marine systems. *Ecology Letters* 9: 228–241.
Harper, D.M., C.D. Smith, and P.J. Barham. 1992. Habitats as the building blocks for river conservation assessment. In *River conservation and management*, ed. P.J. Boon, P. Calow, and G.E. Petts, 311–320. Chichester: Wiley.
Harris, J.H. 1995. The use of fish in ecological assessments. *Australian Journal of Ecology* 20 (1): 65–80.
Harris, G., and A.L. Heathwaite. 2005. Inadmissible evidence: Knowledge and prediction in land and riverscapes. *Journal of Hydrology* 304: 319.
Harriss. 1982. A system for measuring methane fluxes from inland and coastal wetland environments. *Journal of Environmental Quality* 11: 34.

Hart, D.D. 1983. The importance of competitive interactions within stream populations and communities. In *Stream ecology*, ed. J.R. Barnes and G.W. Minshall. New York: Plenum Press.

Haslam, E. 1974. Polyphenol-protein interactions. *The Biochemical Journal* 139: 285–288.

Hamel, P., P. Mangan, P. East, M. Lapointe, and P. Laurendeau. 1997. Comparison of different models to predict the in situ embryonic development rate of fish with special reference to white sucker (Catostomus commersoni). *Canadian Journal of Fisheries and Aquatic Sciences* 54: 190–197.

Hart, P.R., and G.J. Purser. 1995. Effects of salinity and temperature on eggs and larvae of the greenback flounder. *Aquaculture* 136: 21–230.

Hawkins, C.P., and J.K. Furnish. 1987. Are snails important competitors in stream ecosystems? *Oikos* 49: 209–220.

Hazel, J.R. 1995. Thermal adaptation in biological membranes: Is homeoviscous adaptation the explanation? *Annual Review of Physiology* 57: 19–42.

Hazel, J.R., and C.L. Prosser. 1974. Molecular mechanisms of temperature compensations in poikilotherms. *Physiological Reviews* 54: 620–677.

He, B., C. Miao, and W. Shi. 2013. Trend, abrupt change, and periodicity of streamflow in the mainstream of Yellow River. *Environmental Monitoring and Assessment* 185 (7): 6187–6199.

Heaney, S.I., W.J.P. Smyly, and J.F. Talling. 1986. Interactions of physical, chemical and biological processes in depth and time within a productive English Lake during summer stratification. *Internationale Revue der Gesamten Hydrobiologie* 71: 441–494.

Heaney, S.I., W.J.P. Smyly, and J.F. Talling. 1986. Interactions of physical, chemical and biological processes in depth and time within a productive English Lake during summer stratification. *Internationale Revue der Gesamten Hydrobiologie* 71: 441–494.

Helfrich, L.A., and R.J. Neves. 2003. *Freshwater fish biodiversity and conservation*, 420–525. Virginia Tech Publishing.

Helfrich, L. A., R.J. Neves, and J. Parkhurst 2009. Sustaining America's aquatic biodiversity : What is aquatic biodiversity; why is it important ? Virginia cooperative extension programs. Publication, 420–520.

Hewett, S.W., and B.L. Johnson. 1987. *A generalized bioenergetics model of fish growth for microcomputers*, Technical Report WIS-SG -87-245. Madison: University of Wisconsin, Sea Grant Institute.

Hey, R.D. 1992. River mechanics and habitat creation. In *Fisheries in the year 2000*, ed. K.T. O'Grady, A.J.B. Butterworth, and R.P. Spillet, 271–285. Nottingham: Institute of Fisheries Management.

HJORT, J. 1914. Fluctuations in the great fisheries of northern Europe viewed in the light of biological research. *Rapports et Proces-Verbaux des Reunions, Conseil International pour l'Exploration de la Mer* 20: 1–228.

Hockely, D.E., and H. Vav der Sloot. 1991. Long term processes in a stabilised coal-waste block exposed to sea water. *Environmental Science and Technology* 25: 1408–1414.

Hodgson, B.P., and K. O'Hara. 1994. Fisheries management of the Welsh Dee – A regulated river. *Polskie Archiwum Hydrobiologii* 41: 331–345.

Hokanson, K.E.F., and C.H.F. Kleiner. 1974. Effects of constant and rising temperature on survival and developmental rates of embryonic and larval yellow perch, Perca flavescens (Mitchill). In *The early life history of fish*, ed. J.H.S. Blaxter, 437–448. Heidelberg: Spinger.

Holden, A.V. 1965. Contamination of fresh water by persistent insecticides and their effects on fish. *Annals of Applied Biology* 55: 332–335.

Holmes, N.T.H. (1998) A review of river rehabilitation in the UK, 1990–1996. Environment Agency R & D Technical Report W175. Environment Agency, UK.

Hora, S.L., and D.D. Mukherji. 1935. On two new species of cyrinid fishes of Deolali. *Records of the Indian Museum* 37 (II): 375–380.

———. 1953. Table for the identification of Indian fresh water fishes with description of certain families and observations on yhe relative utility of the probable Larvivorous fishes of India. *Health Bulletin No. Malaria Bureau* 4 (ed.3): 1–47.

Houde, E.D. 1989. Comparative growth, mortality, and energetics of marine fish larvae: Temperature and implied latitudinal effects. *Fisheries Bulletin U. S.* 87: 471–495.

Houghton, J.T., ed. 2001. Climate change 2001: The scientific basis: Contribution of working group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change International Panel for Climate Change. Climate Change (I.P.C.C) 2007: Synthesis report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change; Cambridge University Press, Cambridge, UK.

Hounghton, R.A., and G.M. Woodwell. 1989. Global climatic change. *Scientific American* 260 (4): 36–44.

Hrbáček, J. 1958. Typologie und Produktivität der teichartigen Gewässer. *Verh Internat Verein Limnol Journal* 13: 394–399.

Hrbacek, J., M. Dvorakova, V. Korinek, and L. Prochazkova. 1961. Demonstration of the effect of the fish stock on the species composition of zooplankton and the intensity of metabolism of the whole plankton association. *Verhandlungen der Internationalischen Vereinigung für Theoretische und Angewandte Limnologie* 14: 192–195.

Hughes, J.M. 2007. Constraints on recovery: Using molecular methods to study connectivity of aquatic biota in rivers and streams. *Freshwater Biology* 52: 616–631.

Hughes, R.M., and T. Oberdorff. 1997. Applications of IBI concepts and metrics to waters outside the United States and Canada. Corvallis Environmental Research Laboratory.

Hughes, J., P. Inchausti, J. Joshi, J. Norberg, O. Sala, J.B.H. Martiny, B.J.M. Bohannan, J.H. Brown, R.K. Colwell, J.A. Fuhrman, J.L. Green, M.C. Horner-Devine, M. Kane, J.A. Krumins, C.R. Kuske, P.J. Morin, S. Naeem, L. Ovreas, A.L. Reysenbach, V.H. Smith, and J.T. Staley. 2006. Microbial biogeography: Putting microorganisms on the map. *Nature Reviews Microbiology* 4: 102–112.

Hutchinson, G.E., 1957. A treatise on limnology, vol. 1, 1015 pp. New York: Wiley.

Hynes, H.B.N. 1970. *The ecology of running waters*. Toronto: University of Toronto Press.

International Panel for Climate Change. Climate Change (IPCC). 2000. In *Special report on emissions scenarios: A special report of working group III of the fourth assessment report of the Intergovernmental Panel on Climate Change*, ed. N. Nakicenovic and R. Swart. Cambridge/New York: Cambridge University Press.

Irvin, D.N. 1974. Temperature tolerance of early developmental stages of Dover sole, Solea solea (L.). In *The early life history of fish*, ed. J.H.S. Blaxter, 449–463. Heidelberg: Spinger.

Iwama, G.K., P.T. Thomas, R.B. Forsyth, and M.M. Vijayan. 1998. Heat shock protein expression in fish. *Reviews in Fish Biology and Fisheries* 8: 1–22.

Iwama, G.K., M.M. Vijayan, R.B. Forsyth, and P.A. Ackerman. 1999. Heat shock proteins and physiological stress in fish. *American Zoologist* 39: 901–909.

Jaksic, F.M., and R. Medel. 1990. Objective recognition of guilds: Testing for statistically significant species cluster. *Oecologia* 82: 87–92.

Jayaram, K.C. 1999. *The freshwater fishes of the Indian region*. Delhi: Narendra Publishing House.

Jayaram, K.C. 2006. *Catfishes of India*. Delhi: Narendra Publishing House.

———., 2010. The freshwater fishes of the Indian region, Revised Second Edition. Narendra Publishing House, Delhi.

Jayaram, K.C., and K.P. Singh. 1977. On a collection of fish from North Bengal. *Records of the Zoology Survey of India* 72: 243–275.

Jennings, S., S.P.R. Greenstreet, and J.D. Reynolds. 1999. Structural change in an exploited fish community: A consequence of differential fishing effects on species with contrasting life histories. *Journal of Animal Ecology* 68: 617–627.

Jhingran, V.G. 1975. Fish culture in freshwater ponds. In *Fish and fisheries of India*, ed. V.G. Jhingran, 276. Delhi: Hindustan Publishing Cooperation.

Jhingran, V.G. 1983. *Fish and fisheries of India*, 666. New Delhi: Hindustan Publishing Corporation.

Jhingran, A.G. 1988. Potential and scope for development of inland capture fisheries resources of India. In *Conservation and management of inland capture fishery resources*, CICFRI Pub. Bull. No. 57, ed. Arun G. Jhingran and V.V. Sugunan, 7–19.

Jhingran, V.G. 1991a. Fish culture in freshwater ponds. In *Fish and fisheries of India*, ed. V.G. Jhingran, 276–319. Delhi: Hindusthan Publishing Corporation.

———. 1991b. *Fish and fisheries of India*. New Delhi: Hindusthan Publication Corporation.

Jiang, X.H., W.C. Huang, C.M. Liu, and Q. Huang. 2004. Water supply need analysis for the lower Yellow River. *Water International* 29: 415–422.

Johnson, Barry L., William B. Richardson, and Teresa J. Naimo. 1995. Past, present, and future concepts in large river ecology: How rivers function and how human activities influence river processes. *BioScience* 45 (3): 134–141.

Jørgensen, S.E., ed. 2011. *Handbook of ecological models used in ecosystem and environmental management*, 620pp. Boca Raton: CRC Press.

Joy, M.K., and R.G. Death. 2004. Application of the index of biotic integrity methodology to New Zealand freshwater fish communities. *Environmental Management* 34: 415–428.

Junk, W.J., P.B. Bayley, and R.E. Sparks. 1989. The flood-pulse concept in river-floodplain systems. In: Proceedings of the International Large River Symposium (LARS). ed. D.P. Dodge, 110–127. Canadian Special Publication in Fishers and Aquatic Sciences, 106.

Jungwirth, M., O. Moog, and S. Muhar. 1993. Effects of river bed restructuring on fish and benthos of a fifth order stream, Melk, Austria. *Regulated Rivers: Research and Management* 8: 195–204.

Justic, D., N.N. Rabalais, and R.E. Turner. 2005. Coupling between climate variability and coastal eutrophication: Evidence and outlook for the northern Gulf of Mexico. *Journal of Sea Research* 54: 25–35.

Kareiva, P.M., J.G. Kingsolver, and R.B. Huey. 1993. Introduction. In *Biotic interactions and global change*, ed. P.M. Kareiva, J.G. Kingsolver, and R.B. Huey, 1–8. Sunderland: Sinauer.

Karr, J.R. 1981. Assessment of biotic integrity using fish communities. *Fisheries* 6: 21–27.

———. 1991. Biological integrity: A long-neglected aspect of water resource management. *Ecological Applications* 1: 66–84.

———. 1999. Defining and measuring river health. *Freshwater Biology* 41: 221–234.

Karr, J.R., and E.W. Chu. 1998. Sustaining living rivers. *Hydrobiologia* 422-423: 1–14.

Karr, J.R., E.J. Sven, and F. Brian. 2008. *Ecological health indicators. Encyclopedia of ecology*, 1037–1041. Oxford: Aca-Press.

Kerfoot, W.C., and A. Sih, eds. 1987. *Predation: Direct and indirect effects on aquatic communities*. Hanover: University press of New England.

Kerswill, C.J. 1967. Studies on effects of forest sprayings with insecticides, 1952–1963, on fish and aquatic invertebrates in New Brunswick Streams: Introduction and summary. *Journal of the Fisheries Research Board of Canada* 24: 701–708.

Kindle, K.R., and D.H. Whitmore. 1986. Biochemical indicators of thermal stress in *Tilapia aurea* (Steindachner). *Journal of Fish Biology* 29: 243–255.

Kinzig, A.P., S.W. Pacala, and D. Tilman, eds. 2001. *The functional consequences of biodiversity: Empirical progress and theoretical extensions*. Princeton: Princeton University Press.

Kita, J., S. Tsuchida, and T. Setoguma. 1996. Temperature preference and tolerance, and oxygen consumption of the marbled rock-fish, *Sebastiscus marmoratus*. *Marine Biology* 125: 467–471.

Kitchell, J.F., R.V. O'Neill, D. Webb, G. Gallepp, S.M. Bartell, J.F. Koonce, and B.S. Ausmus. 1979. Consumer regulation of nutrient cycling. *Bioscience* 29: 28–34.

Kohler, S.L., and M.A. McPeek. 1989. Predation risk and the foreaging behavior of competiting stream insects. *Ecology* 70: 1811–1825.

Kottelat, M., and T. Whitten. 1996a. *Freshwater biodiversity in Asia with special reference to fish*, World Bank technical paper, 343, 1–59. Washington, DC: World Bank.

———. 1996b. *Freshwater biodiversity in Asia with special reference to fish*, World Bank technical paper No.343, 1–75. Washington, DC: World Bank.

Krause, J.R., K.N. Bertrand, A. Kafle, and N.H. Troelstrup. 2013. A fish index of biotic integrity for South Dakota's Northern Glaciated Plains Ecoregion. *Ecological Indicators* 34: 313–322.

Kronvang, B., L.M. Svendsen, A. Brookes, K. Fisher, B. Moller, O. Ottosen, M. Newson, and D. Sear. 1998. Restoration of the rivers Brede, Cole and Skerne: A joint Danish and British EU-LIFE demonstration project. III. Channel morphology, hydrodynamics and transport of sediment and nutrients. *Aquatic Conservation: Marine and Freshwater Ecosystems* 8: 209–222.

Kutty, M.N. 1968. Respiratory quotient in gold fish and rainbow trout. *Journal of the Fisheries Research Board of Canada* 25: 2689–2728.

———. 1981. Energy metabolism in mullet. In *Aquaculture of Grey mullets*, ed. O.H. Oren, 219–253. London: Cambridge University Press.

Kutty, M.N., and M. Peer Mohamed. 1975. Metabolic adaptations of mullet, Rhinomugil corsula (Hamilton) with special reference to energy utilization. *Aquaculture* 5: 253–270.

Lamberti, G.A., and V.H. Resh. 1983. Stream periphyton and insect herbivores: An experimental study of grazing by a caddisfly population. *Ecology* 64: 1124–1135.

———. 1985. Distribution of benthic algae and macroinvertebrates along a thermal stream gradient. *Hydrobiologia* 128: 13–21.

Lande, R., S. Engen, and B.E. Saether. 2003. *Stochastic population dynamics in ecology and conservation*. Oxford: Oxford University Press.

Lasker, R. 1964. An experimental study on the effect of temperature on the incubation time, development, and growth of pacific sardine embryos and larvae. *Copeia* 2: 399–405.

Lawlor, L.R. 1980. Structure and stability in natural and randomly constructed competitive communities. *American Naturalist* 116: 394–408.

Lawlor, T.E. 2008. Comparative biogeography of mammals. *Biological Journal of the Linnean Society* 28 (1–2): 99–125.

Leopold, L.B., M.G. Wolman, and J.P. Miller. 1964. *Fluvial processes in geomorphology*, 552. San Francisco: Freeman.

Li, T., Xulei Huang, Xiaohui Jiang, and Xingong Wang. 2018. Assessment of ecosystem health of the Yellow River with fish index of biotic integrity. *Hydrobiologia* 814: 31–43.

Liao, J.C. 2002. Swimming in needlefish (Belonidae): Anguilliform locomotion with fins. *Journal of Experimental Biology* 205: 2875–2884.

Lichtenfels, A.J., G. Lorenzi-Filho, E.T. Guimaraes, M. Macchione, and P.H. Saldiva. 1996. Effects of water pollution on the gill apparatus of fish. *Journal of Comparative Pathology* 115: 47–60.

Lin, H., and D. Randall. 1991. Evidence for the presence of an electrogenic proton pump on the trout gill epithelium. *The Journal of Experimental Biology* 161: 119–134.

Lindeman, R.E. 1942. Trophic-dynamic aspect of ecology. *Ecology* 23: 399–418.

Liu, W., T.L. Marsh, H. Cheng, and L.J. Forney. 1997. Characterization of microbial diversity by determining terminal restriction fragment length polymorphisms of gene encoding 16S rRNA. *Applied and Environmental Microbiology* 63: 4516–4522.

Liu, Y., Y. Zhou, W. Ju, J. Chen, S. Wang, H. He, H. Wang, D. Guan, F. Zhao, Y. Li, and Y. Hao. 2013. Evapotranspiration and water yield over China's landmass from 2000 to 2010. *Hydrology and Earth System Sciences* 17 (12): 4957–4980. https://doi.org/10.5194/hess-17-4957-2013.

Lomolino, M.V., J.H. Brown, and R. Davis. 1989. Island biogeography of montane forest mammals in the American southwest. *Ecology* 70: 180–194.

Lotrich, V.A. 1973. Growth, production, and community composition of fishes inhabiting a first, second, and third – Order stream of eastern Kentucky. *Ecological Monograph* 43: 377–397.

Lowe-McConnell, R.H. 1975. *Fish communities in tropical freshwaters*. London: Longman.

Lyons, J. 2012. Development and validation of two fish-based indices of biotic integrity for assessing perennial coolwater streams in Wisconsin, USA. *Ecological Indicators* 23: 402–412.

Lyons, J., S. Navarro-Perez, P.A. Cochran, E.C. Santana, and M. Guzman-Arroyo. 1995. Index of biotic-integrity based on fish assemblages for the conservation of streams and rivers in West - Central Mexico. *Conservation Biology* 9: 569–584.

Mackas, D.L., R.E. Thomson, and M. Galbraith. 2001. Changes in the zooplankton community of the British Columbia continental margin,1985–1999, and their covariation with oceanographic conditions. *Canadian Journal of Fisheries and Aquatic Sciences* 58: 685–702.

Mahanta, P.C., and D. Sharma. 2010. *Coldwater fisheries management*, 1–451. Nainital: DCFR, ICAR.

Maiti Dutta, S., S. Banerjee Mustafi, S. Raha, and S.K. Chakraborty. 2014. Assessment of thermal stress adaptation by monitoring **Hsp70** and **MnSOD** in the freshwater gastropod, *Bellamya bengalensis* (Lamark, 1882). *Environmental Monitoring and Assessment* 186 (12): 8961–8967.

Maiti Dutta, S., Banerjee, S. Mustafi, S. Raha, and S.K. Chakraborty. 2018. Biomonitoring role of some cellular markers during heat stress-induced changes in highly representative fresh water mollusc, *Bellamya bengalensis*: Implication in climate change and biological adaptation. *Ecotoxicology and Environmental Safety* 157: 482–490.

Mann, R.H.K. 1988. Fish and fisheries of regulated rivers in the U.K. *Regulated Rivers: Research and Management* 2: 411–424.

———. 1996. Environmental requirements of European non-salmonid fish in rivers. *Hydrobiologia* 323: 223–235.

Manson, F.J., N.R. Longerman, G.A. Skilleter, and S.R. Phinn. 2005. An evaluation of the evidence for linkages between mangroves and fisheries: A synthesis of the literature and identification of research directions. *Oceanography and Marine Biology: An Annual Review* 43: 485–515.

Manush, S.M., A.K. Pal, N. Chatterjee, T. Das, and S.C. Mukherjee. 2004. Thermal tolerance and oxygen consumption of *Macrobrachium rosenbergii* acclimated to three temperatures. *Journal of Thermal Biology* 29: 15–19.

Manush, S.M., A.K. Pal, T. Das, and S.C. Mukherjee. 2005. Dietary high protein and vitamin C influence in mitigating stress due to chelate claw ablation in Macrobrachium rosenbergii males. *Comparative Biochemistry and Physiology A* 142: 10–18.

Matthews, W.J. 1986. Fish faunal 'breaks' and stream order in the eastern and Central United States. *Environmental Biology of Fishes* 7: 81–92.

Matthews, W.J. 1999. *Patterns in fresh water fish ecology*, 756. London: Chapman and Hall.

Matuszek, J.E. 1978. Empirical predictions of sh yields of large north American lakes. *Transactions of the American Fisheries Society* 107: 385–394.

Mazumder, D., N. Saintilan, and R.J. Williams. 2006. Trophic relationships between itinerant fish and crab larvae in a temperate Australian saltmarsh. *Marine and Freshwater Research* 57 (2): 193–199.

McAulife, J.R. 1983. Competition, colonization patterns and disturbance in stream benthic communities. In *Stream ecology: Application and testing of general ecological theory*, ed. J.R. Barnes and G.W. Minshall, 137–157. New York: Plenum Press.

McHugh, J.L. 1970. Trends in fishery research. *American Fisheries Society. Special Publication* 7: 25–56.

McIntosh, R.P. 1985. *The background of ecology: Concept and theory*. New York: Cambridge University Press.

McKeown, B.A. 1984. *Fish migration*. London: Croom Helm.

McKinnon, J.S., and H.D. Rundle. 2002. Speciation in nature: The three spine stickleback model systems. *Review Trends in Ecology and Evolution*: 1–9.

Meisner, J.D., and B.J. Shuter Dr. 1992. Assessing potential effects of global climate change on tropical fresh water fishes. 28: 21–27.

Menon, A.G.K. 1949. *Notes on fishes XLIV*. Nepal: Fishes from the Koshi Himalayas.

Menon, A.G.K. 1962. A distributional list of fishes of the Himalayas. *Journal of the Zoological Society of India* 14 (1–2): 23–32.

———. 1987. Fauna of India and the adjacent countries: Pisces, Vol. IV; Teleostei – Cobitoidae, Part I, Homalopteridae, Zoological Survey of India.

———. The Fauna of India and adjacent countries . Pisces, Vol. IV; Teleostei – Cobitoidae, Part 2 : Cobitoidae. Zoological Survey of India, Calcutta 113.

———. 1999. Check list fresh water fishes of India. In *Records zoological survey of india*, Occasional Paper No.17, vol. 175, 1–366.

Millennium Ecosystem Assessment. 2005. *Ecosystems and human Well-being: Wetlands and water synthesis*. Washington DC: World Resources Institute.

Ming, Y.C., S.Y. Huang, E.C. Lin, T.H. Hseu, and W.C. Lee. 2003. Association of a single nucleotide polymorphism in the 5'-flanking region of porcine HSP70.2 with Backfat thickness in Duroc breed. *Asian-Australasian Journal of Animal Sciences* 16 (1): 100–103.

Miranda, L.E. 2005. Fish assemblages in oxbow lakes relative to connectivity with the Mississippi River. *Transactions of the American Fisheries Society* 134: 1480–1489.

Mishra, S.S., P. Pradhan, S. Kar, and S.K. Chakraborty. 2003. Ichthyofaunal diversity of Midnapore, Bankura and Hoogly Districts, South West Bengal. Records of the Zoological Survey of India. Occasional Paper No-220:1–65.

Mishra, S.S., S.K. Acharjee, and S.K. Chakraborty. 2009. Development of tools for assessing conservation categories of siluroid fishes of fresh water and brackish water wetlands of South West Bengal, India. *Journal of Environmental Biology of Fishes* 84: 395–407.

Mishra, S., S.K. Chakraborty, S.K. Acharya, and G.C. Mishra. 2017. *Fish diversity and conservation: The approach and strategy*. New-Delhi: Krishi Sanskriti Publication. ISBN: 978-93-85822-20-9.

Mogalekar, Hs, C. Johnson, C.P. Ansar, and D. Bhakta. 2017. Freshwater fish diversity of West Bengal, India. *Journal of Entomology and Zoology Studies* 5 (2): 37–45.

Montgomery, R., R. Dryer, T.W. Conway, and A. Spector. 1980. *Biochemistry a case-oriented approach*. St Louis: The C. V. Mosby Company.

Morita, K., and S. Yamamoto. 2002. Effects of habitat fragmentation by damming on the persistence of stream-dwelling Charr populations. *Conservation Biology* 16 (5): 1318–1323.

Moss, B. 1988. Ecology of fresh waters. Man and medium, 417pp. Oxford: Blackwell Science.

Mouillot, D., S. Spatharis, S. Reizopoulou, et al. 2006. Alternatives to taxonomic-based approaches to assess changes in transitional water communities. *Aquatic Conservation–Marine and Freshwater Ecosystems* 16: 469–482.

Moyle, P.B. 2002. *Inland fishes of California*. Berkeley: University of California Press.

Moyle, P.B., and J.J. Cech. 2000. *Fishes: An introduction to ichthyology*. Pearson.

Munro, A.L.S. 2001. The aquatic environment. In *Fish pathology*, ed. R.J. Roberts, 1–11. London: WB Saunders.

Muotka, T., and P. Laasonen. 2002. Ecosystem recovery in restored headwater streams: The role of enhanced leaf retention. *Journal of Applied Ecology* 39: 145–156.

Murugesan, A.G., and N. Sukumaran. 1999. Impact of urbanization and industrialization on the river Tamirabarani, the lifeline of Tirunelveli and Thoothukudi districts. *Proceedings of Seminar Environment Problm*: 1–14.

National Research Council. 2001. *Compensating for wetland losses under the clean water act*. Washington, DC: National Academy Press.

Norouzitallab, P., M. Farhangi, M. Babapour, R. Rahimi, A.K. Sinha, and K. Baruah. 2008. Comparing the efficacy of dietary a-tocopherol with that of DL-atocopheryl acetate, both either alone or in combination with ascorbic acid, on growth and stress resistance of angelfish, Pterophylum scalare, juveniles. *Aquaculture International*. https://doi.org/10.1007/s10499-008-9192-8.

Northcote, T.G. 1997. Potamodromy in salmonidae: living and moving in the fastlane, North American. *Journal of Fishery and management* 17: 1029–1045.

Naiman, R.J. 1997. Large animals and system-level characteristics in river corridors. *Bioscience* 47: 521–529.

Naiman, R.J., D.G. Lonzarich, T.J. Beechie, and S.C. Ralph. 1992. General principles of classification and the assessment of conservation in rivers. In *River conservation and management*, ed. P.J. Boon, P. Calow, and G.E. Petts, 93–123. Washington DC: American Geophysical Union.

Nelson, J.S. 1984. *Fishes of the world*. 2nd ed, 523. New York: Wiley.

Oberdorff, T., and Jean-Pierre Porcher. 1992. Fish assemblage structure in Brittany streams (France). *Aquatic Living Resources* 5 (3): 215–223.

Oberdorff, T., E. Guilbert, and Jean-Claude Lucchetta. 1993. Patterns of fish species richness in the SeineRiver basin, France. *Hydrologia* 259: 157–167.

Oberdorff, T., P.A. Tedesco, B. Hugueny, F. Leprieur, O. Beauchard, S. Brosse, and H.H. Durr. 2011. Global andregional patterns in riverine fish species richness: A review. *Journal of Ecology* 2011: 1–12.

Odling-Smee, F.J. 1988. Niche-constructing phenotypes. In *The role of behavior in evolution*, ed. H.C. Plotkin, 73–132. Cambridge: MIT Press.

Oglesby, R.T. 1977. Relationships of fish yield to lake phytoplankton standing crop, production, and morphoedaphic factors. *Journal of the Fisheries Board of Canada* 34 (12): 2271–2279.

Ojanguren, A.F., and F. Brana. 2003. Thermal dependence of embryonic growth and development in brown trout. *Journal of Fish Biology* 62: 580–590.

Ojha, J., and S.K. Singh. 2006. Functional morphology of the anchorage system and food scrapers of a hillstream fish, Gara lamta (Ham.) (Cyprinidae, Cypriniformes). *Journal of Fish Biology* 41 (1): 159–161.

Okuda, N., T. Takeyama, T. Komiya, Y. Kato, Y. Okuzaki, J. Karube, Y. Sakai, M. Hori, I. Tayasu, and T. Nagata. 2012. A food web and its long -term dynamics in Lake Biwa: A stable isotope approach. In *Lake Biwa: Interactions between nature and people*, ed. H. Kawanabe, M. Nishino, and M. Maehata, 205–210. Tokyo: Springer.

Okuda, N., Y. Sakai, K. Fukumori, S.M. Yang, C.H. Hsieh, and F.K. Shiah. 2017. Food web properties of the recently constructed, deep subtropical Fei-Tsui reservoir in comparison with the ancient lake Biwa. *Hydrobiologia* 802: 199–210.

Patra, M.K., S.K. Acharjee, and S.K. Chakraborty. 2005a. Methodology for assessing the status of Fish Stock in mangroves. Mangrove Ecosystems: A manual for the assessment of Biodiversity. CMFRI Special Publication No. 83: 219–221.

———. 2005b. Conservation categories of siluroid fishes in north-East Sundarbans, India. *Biodiversity and Conservation* 14: 1863–1876.

Patterson, B.D., and W. Atmar. 1986. Nested subsets and the structure of insular mammalian faunas and archipelagos. *Biological Journal of the Linnean Society* 28: 65–82.

Pearsons, T.N., H.W. Li, and G.A. Lamberti. 1992. Influence of habitat complexity on resistance to flooding and resilience of stream fish assemblages. *Transactions of the American Fisheries Society* 121: 427–436.

Poff, N.L. 1997. Landscape filters and species traits: Toward mechanistic understanding and prediction in stream ecology. *Journal of the North American Benthological Society* 16: 391–409.

Poff, N.L., J.D. Allan, M.B. Bain, J.R. Karr, K.L. Prestegaard, B.D. Richter, R.E. Sparks, and J.C. Stromberg. 1997. The natural flow regime: A paradigm for river conservation and restoration. *Bioscience* 47: 769–784.

Poff, N.L., J.D. Olden, D.M. Merritt, and D.M. Pepin. 2007. Homogenization of regional river dynamics by dams and global biodiversity implications. *Proceedings of the National Academy of Sciences* 104: 5732–5737. https://doi.org/10.1073/pnas.0609812104.

Post, D.M. 2002a. The long and short of food-chain length. *Trends in Ecology and Evolutions* 17: 269–277.

———. 2002b. Using stable isotopes to estimate trophic position: Models, methods, and assumptions. *Ecology* 83: 703–718.

Post, D.M., M.L. Pace, and N.G. Hairston. 2000. Ecosystem size determines food-chain length in lakes. *Nature* 405: 1047–1049.

Power, M.E. 1990. Effects of fish in river food webs. *Science* 250: 811–814.

Power, M.E., W.J. Matthews, and A.J. Stewart. 1985. Grazing minnows, piscivorous bass, and streams algae: Dynamics of a strong interaction. *Ecology* 66: 1448–1456.

Power, M.E., R.J. Stout, C.E. Cushing, P.P. Harper, F.R. Hauer, W.J. Matthews, P.B. Moyle, B. Statzner, and I.R. Wais De Badgen. 1988. Biotic and abiotic controls in river and stream communities. *Journal of the North American Benthological Society* 7: 456–479.

Pradhan, P., and S.K. Chakraborty. 2006. Diversity of zooplanktonic rotifers of river Shilabati, west Midnapore District, West Bengal, India. *Aquacult* 7 (1): 99–117.

Pradhan, P, and S. K. Chakraborty. 2008. Ecological study of rotifera and its application for biomonitoring freshwater riverine environment. Zoological Research in Human Welfare. Paper-31: 289–306.

Punchard, N.T., M.R. Perrow, and A.J.D. Jowitt. 2000. Structure, density and biomass in natural and channelised lowland streams in the catchment of the river Wensum, UK. In *Management and ecology of river fisheries*, ed. I.G. Cowx, 143–157. Oxford: Fishing News Books.

Pal, A.K., and S.C. Mukherjee. 2003. Heat shock protein expression in fish and shellfish: Environmental perspectives and health management. In *Biotechnology in Environemntal Management*, ed. T. Chakrabrti, T.K. Ghosh, and G. Tripathi, 95–116. New Delhi: APH Publishers.

Palmisano, N.A., J.R. Winton, and W.W. Dickhoff. 2000. Tissues specific induction of HSP 90 mRNA and plasma cortisol response in Chinook Salmon following heat shock, sea water challenge and handling challenge. *Marine Biotechnology* 2: 329–338.

Panepucci, L., M.N. Fernandes, J.R. Sanches, and F.T. Rantin. 1999. Changes in lactate dehydrogenase and malate dehydrogenase activities during hypoxia and after temperature acclimation in the armored fish, Rhinelepis strigosa (Siluriformes, Loricariidae). *Brazilian Journal of Biology* 60: 353–360.

Paszkowski, C.A., and M. Tonn William. 2006. Foraging guilds of aquatic birds on productive boreal lakes: environmental relations and concordance patterns. 567: 19–30.

Pawert, M., E. Muller, and R. Triebskorn. 1998. Ultrastructural changes in fish gills as biomarker to assess small stream pollution. *Tissue & Cell* 30: 617–626.

Pearson, T., D. Hyde, and K. Bowler. 1999. Heterologus acclimation: A novel approach to the study of thermal acclimation in the crab *Cancer pagurus*. *American Journal of Physiology Regulatory, Integrative and Comparative Physiology* 277: 24–30.

Pepin, P. 1991. Effect of temperature and size on development, mortality, and survival rates of the pelagic early life stages of marine fish. *Canadian Journal of Fisheries and Aquatic Sciences* 48: 503–518.

Perez-Casanova, J.C., L.O.B. Afonso, S.C. Johnson, S. Currie, and A.K. Gamperl. 2008. The stress and metabolic responses of juvenile Atlantic cod *Gadus morhua* L. to an acute thermal challenge. *Journal of Fish Biology* 72: 899–916.

Philippart, C.J.M., H.M. van Aken, J.J. Beukema, O.G. Bos, G.C. Cadée, and R. Dekker. 2003. Climate-related changes in recruitment of the bivalve Macoma balthica. *Limnology and Oceanography* 48: 2171–2185.

Plafkin, J.L., M.T. Barbour, K.D. Porter, S.K. Gross, and R.M. Hughes. 1989. *Rapid bioassessment protocols for use in streams and rivers: Benthic macroinvertebrates and fish .U.S.* Washington, DC: Environmental Protection Agency, Office of Water Regulations and Standards. EPA 440-4-89-001.

Poff, N.L., M.M. Brinson, and J.W. Day Jr. 2002. *Aquatic ecosystems and global climate change. Potential impacts on inland freshwater and coastal wetland ecosystems in the United States*. Report prepared for the Pew center on Global Climate Change. Also available at www.pewclimate.org.

Ponnuraj, M., A.G. Murugesan, and N. Sukumaran. 2002. Effect of temperature on incubation time, fertilization rate and survival of the spawn of Rohu, Labeo rohita. In *Thermal ecology*, ed. B. Venkataramani and N. Sukumaran, 430–433. Mumbai: BRNS. DAE.

Port, C.B., G.A. Coker, D.L. Ming, and Randall. 2006. *A review of fish sampling methods commonly used in Canadian fresh water habitats*, Canadian Technical Report of Fisheries and Aquatic Sciences, 1–58.

Post, D.M., E.P. Palkovacs, E.G. Schielke, and S.I. Dodson. 2008. Intraspecific variation in a predator affects community structure and cascading trophic interactions. *Ecology* 89: 2019–2032.

Power, M.E. 1990. Effects of fish in river food webs. *Science* 250: 811–814.

———. 1992. Habitat heterogeneity and the functional significance of fish in river food webs. *Ecology* 73: 1675–1688.

Power, M.E., R.J. Stout, C.E. Cushing, P.P. Harper, F.R. Hauer, W.J. Matthews, P.B. Moyle, B. Statzner, and I.R. Wais De Badgen. 1988. Biotic and abiotic con- trols in river and stream communities. *Journal of the North American Benthological Society* 7: 456–479.

Power, M.E., D. Tilman, J.A. Estes, B.A. Menge, W.J. Bond, L.S. Mills, G. Daily, J.C. Castilla, J. Lubchenco, and R.T. Paine. 1996. Challenges in the quest for keystones. *Bioscience* 46: 609–620.

Pradhan, P., S. Giri, and S.K. Chakraborty. 2006. Ecological gradients determining the density and diversity of rotifera in a fresh water river system of South West Bengal, India. *Journal of Aquatic Biology* 21 (1): 19–28.

———. 2008. Zooplanktonic rotifers in river Kansai, West Bengal, India. *Journal of Indian Fisheries Society of India* 39 (2): 43–47.

Probst, W.N., S. Stoll, L. Peters, P. Fischer, and R. Eckmann. 2009. Lake water level increase during spring affects the breeding success of bream Abramis brama (L). *Hydrobiologia* 632: 211–224.

Prosser, C.L., and J.E. Heath. 1991. Temperature. In *Environmental and metabolic animal physiology*, ed. C.L. Prosser, 109–165. New York: Wiley-Liss.

Qasim, S.Z., and R. Sen Gupta. 1981. Environmental characteristics of the Mandovi-Zuari estuarine system in Goa. *Estuarine, Coastal and Shelf Science* 13: 557e578.

Rabeni, C.F., and R.B. Jacobson. 1993. The importance of fluvial hydraulics to fish-habitat restoration in low-gradient alluvial streams. *Freshwater Biology* 29 (2): 211–220.

Reddy, P.K., and T.J. Lam. 1991. Effect of thyroid hormones on hatching in the tilapia, Oreochromis mossambicus. *General and Comparative Endocrinology* 81: 484–491.

Reice, S.R. 1985. Experimental disturbance and the maintenance of species diversity in a stream community. *Oecologia* 67: 90–97.

Reice, S.R., and R.L. Edwards. 1986. The effect of vertebrate predation on lotic macroinvertebrates communities in Quebec, Canada. *Canadian Journal of Zoology* 64: 1930–1936.

Reid, S.D., T.W. Moon, and S.F. Perry. 1992. Rainbow trout hepatocyte b adrenoceptors, catcholamine responsiveness, and effects of cortisol. *American Journal of Physiology* 262: 794–799.

Reubush, K.J., and A.G. Heath. 1996. Metabolic responses to acute handling by fingerling inland and striped bass. *Journal of Fish Biology* 49: 830–841.

Richman, N.H.I., S. Tai de Diaz, R.S. Nishioka, P.I. Punet, and H.A. Bern. 1987. Osmoregulatory and endocrine relationships with chloride cell morphology and density during smoltification in coho salmon, (Oncorhynchus kisutch). *Aquaculture* 60: 265–285.

Roberts, H.H. 1998. Delta switching: Early responses to the Atchafalaya River diversion. *Journal of Coastal Research* 14: 882–899.

Roots, B.J. 1965. Phospholipids of goldfish (Carassius auratus) brain: The influence of environmental temperature. *Comparative Biochemistry and Physiology* 25: 457–466.

Rothschild, B.J. 1986. *Dynamics of marine fish populations*, 1–277. Cambridge: Harvard University Press.

Ryder, A. 1965. A method for estimating the potential sh production of north-temperate lakes. *Transactions of the American Fisheries Society* 94: 214–218.

Ravindra, K., Ameena, Meenakshi, Monika, Rani, and A. Kaushik. 2003. Seasonal variations in physicochemical characteristics of river Yamuna in Haryana and its ecological best designated use. *Journal of Environmental Monitoring* 5: 419–426.

Rawson, D.S. 1939. Some physical and chemical factors in the metabolism o f lakes. In: E.R. Moulton, ed., Problems of lake biology. Publ. 10, AAAS, Washington, D.C. pp. 9–26.

———. 1952. Mean depth and the fish production of large lakes. *Ecology* 33: 513–521.

Risser, P.G., J.R. Karr, and R.T. Forman. 1984. Landscape ecology-directions and approaches. Illinois Natural History Survey Special Publication No. 2, Champai.

Robinson, R.A., and W.J. Sutherland. 2002. Post-war changes in arable farming and biodiversity in Great Britain. *Journal of Applied Ecology* 39 (1): 157–176.

Root, R.B. 1967. The niche exploitation pattern of the blue–gray gnatcatcher. *Ecological Monographs* 37: 317–350.

RRC. 1999. Manual of river restoration techniques. River Restoration Centre, UK.

Ruaro and Gubiani. 2013.

Ryder, A. 1965. A method for estimating the potential fish production of north-temperate lakes. *Transactions of the American Fisheries Society* 94: 214–218. Robinson & Sutherland.

Sanchez-Choliz, J., and R. Duarte. 2003. Analyzing pollution by way of vertically integrated coefficients, with an application to the water sector in Aragon. *Cambridge Journal of Economics* 27 (3): 433–448.

———. 2005. Water pollution in the Spanish economy: Analysis of sensitivity to production and environmental constraints. *Ecological Economics* 53: 325–338.

Sanders, B.M. 1993. Stress proteins in aquatic organisms: An environmental perspective. *Critical Reviews in Toxicology* 23: 49–75.

Saravanan, T.S., M.A. Mohamed, R. Chandrasekar, and M. Sundramoorthy. 2003. Freshwater fishes as indicators of Kaveri river pollution. *Journal of Environmental Biology* 24 (4): 381–389.

Sargaonkar, A.P., R. Vijay, and A. Gupta. 2006. Quantitative assessment of annual runoff in sub-catchments using GIS: a case study of Tapi River Basin, India. *International Journal of Environmental Studies* 63: 189–199.

Saunders, D.L., J.J. Meeuwig, and A.C.J. Vincent. 2002. Freshwater protected areas: Strategies for conservation. *Conservation Biology* 16 (1): 30–41.

Sayer, M.D.J., and J. Davenport. 1987. The relative importance of the gills to ammonia and urea excretion in five seawaters and one freshwater teleost species. *Journal of Fish Biology* 31: 561–570.

Schallenberg, M., U. Friedrich, and C.W. Burns. 2001. Postulated responses of phytoplankton and bacteria to predicted increases of inorganic suspended sediments in oligotrophic lakes. *New Zealand Journal of Marine and Freshwater Research* 35: 763–779.

Schiemer, F., T. Spindler, H. Wintersberger, A. Schneider, and A. Chovanec. 1991. Fish fry associations: Important indicators for the ecological status of large rivers. *International Vereiningung fuer Theoretische und Angewandte Limnologie Verhandlungen* 24: 2497–2500.

Schlee, J. 1973. *Atlantic Continental Shelf and Slope of the United States -Sediment Texture of the Northeastern part*, Professional Paper 529 -L, 1–64. U.S. Geological Survey.

Schlesinger, M.J., M. Ashburner, and Tissieres. 1982. *Heat shock proteins from bacteria to man*, 243–251. New York: Cold Springe Harbor Lab Press.

Schmitz, O.J. 2006. Predators have large effects on ecosystem properties by changing plant diversity, not plant biomass. *Ecology* 87: 1432–1437.

———. 2008. Herbivory from individuals to ecosystems. *Annual Review of Ecology and Systematics* 39: 133–152.

———. 2010. *Resolving ecosystem complexity*. Princeton: Princeton University Press.

Sedell, J.R., J.E. Richey, and F.J. Swanson. 1989. The river continuum concept: A basis for the expected ecosystem behavior of very large rivers? *Canadian Special Publication of Fisheries and Aquatic Sciences* 106: 110–127.

Sheridan, M.A. 1994. Regulation of lipid metabolism in poikilothermic vertebrates. *Comparative Biochemistry Physiology B* 107: 495–508.

Simberloff, D. 2009. We can eliminate invasions or live with them. Successful management projects. *Biological Invasions* 11: 149–157.

Simmons, C.E. 1987. *Sediment characteristics of North Carolina streams 1970–1979*, 87–701. U. S. Geological Survey Open-File report.

Snyder, N.P., K.X. Whipple, G.E. Tucker, and D.J. Merritts. 2003. Channel response to tectonic forcing: field analysis of stream morphology and hydrology in the Mendocino triple junction region, northern California. *Geomorphology* 53: 97–127.

Stevens, E.D., and A.M. Sutterlin. 1976. Heat transfer between fish and ambient water. *Journal of Experimental Biology* 65: 131–145.

Stout, J., and J. Vandermeer. 1975. Comparison of species richness for stream -inhabiting insects in tropical and mid- latitude streams. *American Naturalist* 109: 263–280.

Straub, C.S., and W.E. Snyder. 2006. Species identity dominates the relationship between predator biodiversity and herbivore suppression. *Ecology* 87: 277–282.

Straub, C.S., D.L. Finke, and W.E. Snyder. 2008. Are the conservation of natural enemy biodiversity and biological control compatible goals ? *Biological Control* 45 (2): 225–237.

Subasinghe, R.P., and C. Sommerville. 1992. Effects of temperature on hatchability, development and growth of eggs and yolk-sac fry of *Orechromis mossambicus* (Peters) under artificial incubation. *Aquaculture and Fisheries Management* 23: 31–90.

Sudarman, A., and T. Ito. 2000. Heat production and thermoregulatory responses of sheep fed different roughage proportion diets and intake levels when exposed to a high ambient temperature. *Asian-Australasian Journal of Animal Sciences* 13 (5): 625–629.

Sunkad, B.N., and H.S. Patil. 2004. Water quality assessment of fort lake of Belgaum (Karnataka) with special reference to zooplankton. *Journal of Environmental Biology* 25 (1): 99–102.

Sweeney, S. 2000. *Restoration of the environment: Social movement, adaptive culture, emerging science*. Olomouc: University of Olomouc Press.

Syvitski, J.P.M., C.J. Vörösmarty, A.J. Kettner, and P.A. Green. 2005. Impact of humans on the flux of terrestrial sediment to the global coastal ocean. *Science* 308 (5720): 376–380.

Sala, O.E., F.S. Chapin, J.J. Armesto, E. Berlow, J. Bloomfield, R. Dirzo, et al. 2000. Global biodiversity scenarios for the year 2100. *Science* 287 (5459): 1770–1774.

Schleiger, S.L. 2000. Use of an index of biotic integrity to detect effects of land uses on stream fish communities west-Central Georgia. *Transactions of the American Fisheries Society* 129: 1118–1133.

Schlesinger, D.A., and H.A. Regier. 1982. Climatic and morphoedaphic indices of fish yields from natural lakes. *Transactions of the American Fisheries Society* 111: 141–150.

Schram, H., and M. Eggleton. 2006. Applicability of the flood pulse concept in a temperate floodplain river ecosystem thermal and temporal components. *River Research and Applications* 22: 543–553.

Schubauer, J.P., and C.S. Hopkinson. 1984. Above- and below-ground emergent macrophyte production and turnover in a coastal marsh ecosystem, Georgia. *Limnology and Oceanography* 29: 1052–1065.

Shapiro, L. 1975. Rapid analysis of silicate, carbonate and phosphate rocks, Rev. ed. USGS Bulletin 1401.

Shapiro, J., and D.I. Wright. 1984. Lake restoration by biomanipulation. *Freshwater Biology* 14: 371–383.

Shearer, J.S., and C.R. Berry Jr. 2002. Index of biotic integrity utility for the fishery of the James River of the Dakotas. *Journal of Freshwater Ecology* 17 (4): 575–588.

Simon, T., and R. Sanders. 1999. Applying an index of biotic integrity based on great river fish communities: considerations in sampling and interpretation. Assessing the sustainability.

Simonson T.D., J. Lyons, and P.D. Kanehl. 1994. Guidelines for evaluating fish habitat in Wisconsin Streams, General technical report NC-164, 36 pp. United States Department of Agriculture, Forest Service, North Central Forest Experiment Station. St. Paul, Minnesota, USA.

Smith, C.D., P.J. Barham, andD. M. Harper. 1990) River Welland Environmental Survey. NRA (Anglian Region) & Leicester University.

Snyder, R.E., and C.P. Chesson. 2004. How the spatial scales of dispersal, competition, and environmental heterogeneity interact to affect coexistence. *American Naturalist* 164: 633–650.

Snyder, W.E., and A.R. Ives. 2003. Interactions between specialist and generalist natural enemies: Parasitoids, predators, and pea aphid biocontrol. *Ecology* 84: 91–107.

Snyder, W.E., G.B. Snyder, D.L. Finke, and C.S. Straub. 2006. Predator biodiversity strengthens herbivore suppression. *Ecology Letters* 9: 789–796.

Sommer, T.R., R.D. Baxter, and F. Feyrer. 2007. Splittail "delisting": A review of recent population trends and restoration activities. *American Fisheries Society Symposium* 53 (25): 38.

Spillet, P.B., G.S. Armstrong, A. G. Magrath, and J.S. Alabaster. 1985. Ameliorative methods to reinstate fisheries following land drainage operations.

Stoddard, J.L., D.P. Larsen, C.P. Hawkins, R.K. Johnson, and R.H. Norris. 2006. Setting expectations for the ecological condition of streams: the concept of reference condition.

Swales, S. 1989. The use of instream habitat improvement methodology in mitigating the adverse effects of river regulation on fisheries. In *Alternatives in regulated river management*, ed. J.A. Gore and G.E. Petts, 186208. Boca Raton: CRC Press.

Swales, S., F. Caron, J.R. Irvine, and C.D. Levings. 1988. Overwintering habitats of coho salmon (Oncorhynchus kisutch) and other juvenile salmonids in the Keogh River system, British Columbia. *Canadian Journal of Zoology* 66 (1): 254–261.

Taylor, E.B. 1999. Species pairs of north temperate freshwater fishes: Evolution, taxonomy, and conservation. *Reviews in Fish Biology and Fisheries* 9 (4): 299–324.

Taylor, S.G. 2007. Climate warming causes phenological shift in Pink Salmon, Oncorhynchus gorbuscha, behavior at Auke Creek, Alaska. *Global Change Biology* 14: 229–235.

Taylor, M.H., and M. Wolff. 2007. Trophic modelling of eastern boundary current systems: A review and prospectus for solving the "Peruvian puzzle". *Revista Peruana de Biología* 14: 87–100.

Tort, L. 2011. Stress and immune modulation in fish. *Developmental and Comparative Immunology* 35: 1366–1375.

Talwar, P.K. 1991. *Pisces. Animal resources of India, Protozoa to Mammalia*, 577–630. Calcutta: Zoological Survey of India.

Talwar, P. K., and Kacker, R.K. 1984. Commercial Sea fishes of India. Zoological Survey of India, Calcutta, 977.

Taylor. 1980. Methane cycling in aquatic environments. *Advances in Aquatic Microbiology* 2: 77–150.

Tripathi, S.D. 2009 Should Indian aquaculture continue to depend on exotic species? No. In: Aquaculture Management (eds. Goswami, U.C. and Kumar, D). 59–70. Narendra Publishing House.

Townsend, C.R., and A.G. Hildrew. 1994. Species traits in relation to a habitat templet for river systems. *Freshwater Biology* 31 (3): 265–275.

United Nations Conference on Environment and Development (UNCED).1992. *Agenda 21*. A/ CONF.15/14, United Nations, New York, June.

Van deWolfshaar, K.E., H. Middelkoop, E. Addink, H.V. Winter, and L.A.J. Nagelkerke. 2011. Linking flow regime, floodplain lake, connectivity and fish catch in a large River-Floodplain system, the Volga-Akhtuba Floodplain (Russian Federation). *Ecosystems* 14: 920–934.

VanDerWal, J., L.P. Shoo, C.N. Johnson, et al. 2009. Abundance and the environmental niche: Environmental suitability estimated from niche models predicts the upper limit of local abundance. *The American Naturalist* 174: 282–291.

Vandewalle, M., Francesco de Bello, P.B. Matty, B. Thomas, D. Sylvain, D. Florence, K.F. Christian, H. Richard, A.H. Paula, L. Sandra, Pedro Martins da Silva, M. Marco, N. Jari, S. Paulo, S.J. Thomas, S. Paulo, T.S. Martin, J.V. Adam, and A.V. Ben. 2010. Functional traits as indicators of biodiversity response to land use changes across ecosystems and organisms. *Biodiversity and Conservation* 19 (10): 2921–2947.

Vanni, M.J. 2002. Nutrient cycling by animals in fresh water ecosystems. *Annual Review of Ecology and Systematics* 33 (1): 341–370.

Vannote, R.L., G.W. Minshall, K.W. Cummi, J. Sedell, and C.E. Cushing. 1980. The river continuum concept. *Canadian Journal Fisheries and Aquatic Sciences* 37: 130–137.

Vaughan, I.P., M. Diamond, A.M. Gurnell, K.A. Hall, A. Jenkins, N.J. Milner, L.A. Naylor, D.A. Sear, G. Woodward, and S.J. Ormerod. 2007. Increasing ecology with hydromorphology: A priorityfor river science and management. *Aquatic Conservation: Marine and Freshwater Ecosystems* 19: 113–125.

Verbost, P.M., T.J.M. Schoenmakers, G. Flik, and S.E. Wendelaar Bonga. 1994. Kinetics of ATP and Na+ gradient driven Ca+2 transport in basolateral membranes from gills of freshwater and seawater adapted tilapia. *The Journal of Experimental Biology* 186: 95–108.

Vickery, P.D., Pl Tubaro, J.M.C. da Siva, B.G. Peterjohn, J.R. Herkert, and R.B. Cavalcanti. 1999. Conservation of grassland birds in the western hemisphere. *Studies in Avian Biology* 19: 2–26.

Vijayan, M.M., and J.F. Leatherland. 1992. In vivo effects of steroid analogue RU485 on some aspects of intermediary and thyroid metabolism of brook charr, Salvelinus fontinalis. *Journal of Experimental Zoology* 263: 265–271.

Vijayan, M.M., and T.W. Moon. 1994. The stress response and plasma disappearance of corticosteroid and glucose in a marine teleost, the sea raven. *Canadian Journal of Zoology* 72: 379–386.

Vijayan, M.M., G.D. Foster, and T.W. Moon. 1993. Cortisol implantation alters hepatic metabolism and hormonal responsiveness in the sea raven. *Fish Physiology and Biochemistry* 12: 327–335.

Vijayan, M.M., P.K. Reddy, J.F. Leatherland, and T.W. Moon. 1994. The effects of cortisol on hepatocyte metabolism in rainbow trout: A study using the steroid analogue RU486. *General Comparative Endocrinology* 96: 75–84.

Vondracek, B., K.L. Blann, C.B. Cox, J.F. Nerbonne, K.G. Mumford, B.A. Nerbonne, L.A. Sovell, and J.K.H. Zimmerman. 2005. Land use, spatial scale, and stream systems: Lessons from an agricultural region. *Environmental Management* 36 (6): 775–791.

Wagner, E.J., T. Bosakowski, and S. Intelmann. 1997. Combined effects of temperature and high pH on mortality and the stress response of rainbow trout after stocking. *Transactions of the American Fisheries Society* 126: 985–998.

Waide, R.B., M.R. Willig, C.F. Steiner, G. Mittelbach, L. Gough, S.I. Dodson, G.P. Juday, and R. Parmenter. 1999. The relationship between productivity and species richness. *Annual Review of Ecology and Systematics* 30: 257–300.

Walde, S.J. 1986. Effect of an abiotic disturbance on a lotic predator -prey interaction. *Oecologia* 69: 243–247.

Wang, P., and P.Y. Vasilevskiy. 2017. Estimating groundwater-ephemeral stream exchange in hyper -arid environments: Field experiments and numerical simulations. *Journal of Hydrology* 555: 68–79.

Wang, L., J. Lyons, P. Rasmussen, P. Seelbach, T. Simon, M. Wiley, P. Kanehi, E.D. Baker, S. Niemela, and P.M. Stewart. 2003. Watershed, reach and riparian influence on stream fish assemblages in the Northern Lakes and forest ecoregion, U.S.A. *Canadian Journal of Fisheries and Aquatic Sciences* 60 (5): 491–505.

Watson, R.T., M.C. Zinyowera, and R.H. Moss, eds. 1997. *IPCC special report on the regional impacts of climate change: An assessment of vulnerability*, 517. Cambridge: Cambridge University Press.

Weber, J., and G. Zwingelstein. 1995a. Circulatory substrate flux and their regulation. In *Biochemistry and molecular biology of fishes*, ed. P.W. Hochachka and T.P. Mommsen, vol. 4, 15–33. Amsterdam: Elsevier.

———. 1995b. Circulatory substrate flux and their regulation. In *Biochemistry and molecular biology of fishes, Vol. 4*, ed. P.W. Hochachka and T.P. Mommsen, 15–33. Amsterdam: Elsevier.

Wedemeyer, G.A. 1976. Physiological response of juvenile coho salmon (Oncorhynchus kisutch) and rainbow trout (Salmo gairdneri) to handling and crowding stress in intensive fish culture. *Journal of the Fisheries Research Board of Canada* 33: 2699–2702.

Wedemeyer, G.R., F.P. Meyer, and L. Smith. 1999a. *In: Environmental stress and fish diseases*, 107. Delhi: Narendra Publishing House.

———. 1999b. *Environmental stress and fish diseases*, 107. Delhi, India: Narendra Publishing House.

Wei, Q., Ke Fu'en, J. Zhang, P. Zhuang, J. Luo, R. Zhou, and W. Yang. 1997. Biology, fisheries and conservation of sturgeons and paddle fish in China. *Environmental Biology of Fishes* 48: 241–255.

Weyand, M., and D. Schitthelm. 2006. Good ecological status in a heavily urbanised river: Is it feasible ? *Water Science and Technology* 53 (10): 247–253.

Whitten, A.J., R.E. Soeriaatmajdja, and S. Afiff. 1996. *The ecology of Java and Bali*. Singapore: Periplus.xx + 946 pp.

Wiens, J.A. 1989. Spatial scaling in ecology. *Functional Ecology* 3: 385–397.

———. 2002. Riverine landscapes: Taking landscape ecology into the water. *Freshwater Biology* 47: 501–515.

Wilcox, T.M., and M.K. Schwartz. 2016. Understanding environmental DNA detection probabilities: A case study using a stream-dwelling char Salvelinus fontinalis. *Biological Conservation* 194: 209–216.

Wilson, R.W., and E.W. Taylor. 1993. The physiological responses of freshwater rainbow trout, Onchorynchus mykiss, during acute exposure. *Journal of Comparative Physiology* 163: 38–47.

Winemiller, K.O., J.V. Montoya, C.A. Layman, D.L. Roelke, and J.B. Cotner. 2006. Experimental demonstrations of seasonal fish effects on benthic ecology of a Neotropical floodplain river. *Journal of the North American Benthological Society* 25: 250–262.

Wang, G.L., L.M. Ma, J.H. Sun, and G. Zhang. 2010. Occurrence and distribution of organochlorine pesticides (DDT and HCH) in sediments from the middle and lower reaches of the Yellow River, China. *Environmental Monitoring and Assessment* 168 (1–4): 511–521.

Ward, J.V., and K. Tockner. 2001. Biodiversity: Towards a unifying theme for river ecology. *Freshwater Biology* 46: 807–819.

Welcomme, R., and A. Halls. 2004. Dependence of tropical river fisheries on flow. In Proceedings of the Second International Symposium on the Management of Large Rivers For Fisheries 2.

Wilcock, D.N., and C.I. Essery. 1991. Environmental impacts of channelization on the river Main, county Antrim, Northern Ireland. *Journal of Environmental Management* 32 (2): 127–143.

Wootton, R.J. 1990. *Ecology of teleost fishes*, Fish and fisheries series. Vol. 1, 404. London: Chapman & Hall.

Xu, J., and Y. Ma. 2009. Response of the hydrological regime of the Yellow River to the changing monsoon intensity and human activity. *Hydrological Sciences Journal* 54 (1): 90–100.

Yoder, C.O., and E.T. Rankin. 1995. Biological response signatures and the area of degradation value: New tools for interpreting multimetric data. In *Biological assessment and criteria: Tools for*, ed. W.S. Davis and T.P. Simon.

Zelinka, M. 1977. The production of Ephemeroptera in running waters. *Hydrobiologia* 56: 121–125.

———. 1979. Differences in the production of mayfly larvae in partial habitats of a barbel stream. *Archiv Hydrobiologia* 90: 284–297.

Zhu, S.Q. 1995. *Synopsis of freshwater fishes of China*, 1–549. Nanjing: Jiangsu Science and Technology Publishing House.

Zhu, D., and J. Chang. 2008. Annual variations of biotic integrity in the upper Yangtze River using an adapted index of biotic integrity (IBI). *Ecological Indicators* 8: 564–572.

Zobel, M. 1997. The relative role of species pools in determining plant species richness. An alternative explanation of species coexistence? *Trends in Ecology & Evolution* 12 (7): 266–269.

Zulkifli, I., S.A. Mysahra, and L.Z. Jin. 2004. Dietary supplementation of betaine (betafin) and response to high temperature stress in male broiler chickens. *Asian-Australasian Journal of Animal Sciences* 17 (2): 244–249.

Chapter 4
Diversity and Conservation of Wildlife Associated with Rivers: An Eco-ethological Analysis

Abstract Wildlife literally means the life-forms (animals and plants) living in the wild without getting any support from the human beings. It can be defined as those plants or animals successfully living in the wild condition from birth to death, excluding humans and domesticated forms or cultivated forms of life as fish. In its most simplistic representation, **"wildlife"** includes only wild mammals, birds, reptiles, and amphibians as forests along with their plants mostly remain under the managerial control by human beings.

A multitude of wildlife-mediated economic, ecological, and social services and values are particularly worthy of mention in India, which hardly attach preeminence to consuming available resources for meeting the needs of human beings. The complexities of ecosystems through their functioning not only support wildlife but also maintain water quality, provide avenues for the growth and biological production of aquatic organisms, and also maintain the ecological stability and environmental equilibrium. Earlier human perception of wildlife was mostly as means of amusement and sources of recreation which has now been changed considerably putting more emphasis on the roles of wildlife as an integral component of ecosystem functioning on one hand and their intrinsic values (the aesthetic values) embedded in the urges of the peoples to have an understanding of the beauty, grace, and complexity of wildlife across all strata of the human civilization on the other. At last, it can be inferred that the continuous and steady interactions of wildlife with their ecosystem set the platform upon which continuous evolutionary processes of life are carried out. An evolutionary interpretation in a logical manner of the seemingly strange and varied morphological and behavioral manifestations of the diversity of wildlife helps better understand the process of origin and existence of diverse forms of wild fauna.

India and its neighboring countries constitute a unique subcontinent having tropical climatic conditions supporting massive vegetational assemblages in the forms of forests (tropical, moist evergreens, tropical deciduous, coniferous, mangroves), scrublands, grasslands, etc. which in turn provide shelter and foods for an innumerable number of wild fauna. Marked differences in the landscapes along with the vegetations have been noted while descending from the Himalayas to the plains of Ganges. The entire area of the middle and lower portions of the Gangetic Plain has

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tropical evergreen forests which extend to the eastern Himalayas and also to the states of Assam, northeastern part of West Bengal, and the slopes of the Himalayas of other northeastern states of India along the mighty river of Brahmaputra. The entire area has become the home of so many interesting and diversified forms of wild fauna experiencing a lot of ecological heterogeneities, structured by the prevailing monsoon-based climatic conditions. The entire Ganga plain in its low altitude has open savannah intermingling with the open forests and low trees supporting so many herbivores like elephants, sambar deers, wild boars, and specially chital deers which in turn cater to the needs of other carnivores.

In the context of the changing diversity of wild fauna in tune with the changes of the riverine landscapes, their adaptive strategies, behavioral manifestations, and interactions with the prevailing environmental conditions in the evolutionary perspectives, the present chapter has included not only diversity of wildlife in India but also the functional relationships of wildfaunal components of with riverine and associated ecosystems pointing out the existing conservation strategies.

Keywords Wildlife · Concept and definition · Values of wildlife · Old World vs New World · Tropical climates · Diversity of landscapes · Habitats and wildlife in India · Bio-ecological uniqueness of wildlife · Wildlife of riparian ecosystem · Historical treatise of Indian wildlife wealth · Jim Corbett · Behavioral ecology of wildlife · Wildlife vs endemism · Threatened wildlife of India · Conservation strategies

4.1 Definition and Relevant Discourses on the Concept of Wildlife

In general, **"wildlife"** means all wild animals and their associated habitats, thereby referred to as all wild and undomesticated animals in their habitats. **The Wildlife (Protection) Act** of India, **1972**, recommended to include all life-forms living in wild conditions such as insects (bees, butterflies, and moths), crustaceans, fish, and all types of noncultivable vegetations (aquatic and terrestrial) forming the integral part of global environment. However, the meanings and expression of the term **"wildlife"** vary according to the changing perspectives, often not implying any uniform meaning. All those discourses have made it really difficult to properly define the term wildlife which according to the noted wildlife conservationist Gee (1964) is that wildlife embraces all living creatures which demand their conservation. Summing up all these propositions, wildlife can be defined as those animals and plants whose populations have emerged under natural evolutionary forces like natural selection or genetic drift, unlike domesticated ones which in contrast evolved by the forces of artificial selection by human beings. In simpler way, the wild animals are those animals whose survival does not depend upon human being and also whose reproduction and growth are not controlled by human being. In contrast, survival, reproduction, and growth of domesticated animals are directly under human control (Driscoll et al., 2009; Wildlife (Protection) Act, 1972, NWAP, 2002).

4.2 Wildlife and Their Dependence on River

4.2.1 The Living Planet: The Key Driver for Environmental Sustainability

E. O. Wilson (1992), one of the renowned naturalists of the world, put forward the view that "**keeping pace with the fast changing patterns of the world environment, there should have been a window of opportunity that would close in as little time as the next two or three decades**". While Wilson's main concern is the rapid loss of biodiversity, he could have added more on climate change or wetlands destruction or deforestation etc as the contributing factors for imposing threats to the biological wealth of the world. The earth has been suffering the most massive extinction of species since the die-off of dinosaurs **65** million years ago. Wilson also contended that continuation of present trend of deforestation and destruction of other major ecosystems of the world such as rain forests, coral reefs, etc., the reservoirs of the world's biodiversity wealth, the mother earth will certainly lose more than half of all the species of plants and animals on earth by the end of the twenty-first century. Today, two chief life-supporting ecological goods, i.e., clean air and drinkable water, do not augur well for our future health and well-being. Many people assume that the enactment of the **Clean Air Act of 1970** usher a new age. It is being contemplated that people can either take up a spiritual path to achieve the goals of conservation or a pragmatic one for the sane objectives but both the ventures are to be arrived, at the same destination. In the **1980s**, E. O. Wilson, recognized as the "**father**" of the term biodiversity, helped bring the term biodiversity into public discussions about conservation. Biodiversity, short for "**biological diversity**," refers to the levels of organization for living things. Living organisms are divided and categorized into ecosystems (such as rain forests or oceans), by species (such as mountain gorillas), and by genetics (the genes responsible for inherited traits). Wilson has predicted that destruction of habitats and pollution of earth are continued at the earth at the current rate, in the coming **50** years, around **30–50%** of the planet's species will face extinction. In the book written by E.O.Willson, entitled *The Diversity of Life*, and published in the year **1992**, it was stated, "**Why should we care?**". (Wilson (1988a); Wilson, 1975, 1992, 1997, 1998; Wilson and Reeder, 1993; Wilson et al., 2007; Li et al. (2018); Schmitz (2006); Schmitz (2008); Schmitz (2010); Schram and Eggleton (2006); Seegert (2000); Shearer and Berry Jr (2002),

4.3 Biodiversity and Conservation of Wildlife

Biodiversity, short for "**biological diversity**," is organized into three levels: ecosystems (e.g., rain forests or deserts), species (the organisms in an ecosystem – humans or red maple trees are examples), and the variety of genes that make up the organisms (genes are responsible for heredity). Wilson has predicted that if humans keep altering the earth, we could lose one-fifth, or **20%**, or more of our plant and animal biodiversity by the year **2020**. Earth's biodiversity has not been saved – not yet. Uncounted species are endangered, flickering out of existence in large numbers before they can even be named. But the man had tried to focus society's attention on the value of biological diversity and the threats to it. Wilson's campaign on behalf of the living world has helped make the conservation movement's goals attainable. Conservation considers the issues that affect our world's vast array of living creatures and the land, water, and air they need to survive.

In the **1960s**, biologist Rachel Carson's book, *Silent Spring* published in the year 1962, brought conservation issues into the public eye. People began to see that polluted land, water, and air affected their health. With the establishment of the US Environmental Protection Agency (**EPA**) in the year **1970**, passage of many federal and state rules and regulations to protect and also to enrich the quality of global environment were facilitated. E. O. Wilson in the year **1992** brought public awareness of conservation issues to a new level proposing caution that the mother earth will experience a lot of environmental odds such as loss of biodiversity, depletion of energy resources, economic collapse, initiation of wars, expansion of totalitarian governments, etc., even many of such are already well underway

It is worth our time to consider the thoughts of two American conservationists and what role we, as individuals, can play in conserving and protecting our world. E. O. Wilson, 1992 advocated that **"Biological diversity**", as **'biodiversity'** in the new parlance, is the key to the maintenance of the world as we know it. Aldo Leopold, the forester who gave Americans the idea of creating a "**land ethic**," wrote in 1949 that: **"Having to squeeze the last drop of utility out of the land has the same desperate finality as having to chop up the furniture to keep warm**." All of the human populations have the ability to take part in the struggle to protect our environment and to save our endangered earth.

4.4 The Diversity of Life in the River

The character of the river changes down its length and with the change of physical characteristics along with a change in the diversity and life patterns of flora and fauna. The headwaters and side tributaries typically run in deep-cut valleys, enjoying the cool and oxygenated fast-flowing water with stony bottom with least deposition of silts and clays on the sediment. The bottom of the flowing water with the pronounced presence of sands and gravels without that much of mud does support the growth of water vegetation in small numbers without almost negligible settlement and growth of some benthic algae and fungi.

The animals in the lotic headwaters have developed the adaptive features in order to reduce the risk of not being washed away with flattened bodies and morphological structures for adhering strictly to the surface of the stones. Some make use of the current to provide them with food adopting filter feeding mechanism. Typical fish of the headwaters are endowed with the streamlined body, strong ability of swimming, and the power of negotiating the velocity of water. Those fishes grow well in the water having low temperatures, higher oxygen concentration, organic food particles, and clean gravels uncontaminated with mud for not only temporary shelter but also for spawning. The lower reaches of a large river present a very different kind of habitats where the current becomes very feeble and the bottom experiences a lot of silt deposition forming thick mud triggering the growth and propagation of a variety of hydrophytes of different shapes and sizes. All deep-bodied fishes having poor swimming efficiencies are adapted in the warmer water loaded with variety of living and nonliving food particles.

Maintenance of the health of the river by a myriad of activities and interlinkages of most of the true riverine organisms (plankton, benthos, hydrophytes, fishes, etc.) with each other through such activities ultimately attract a galaxy of other larger animals (amphibians, reptiles, birds, and mammals) not only from the riparian forests but also from the remote ecozones in search for the water, food, and shelter, which in turn contribute for the enrichment of the river ecosystem by providing necessary inputs. Hutchinson (1957); Huxley (1973); Wilson (1988a); Wilson, 1992, 1997, 1998; Wilson and Reeder, 1993; Wilson et al. (2007); Anon, 1991; Winemiller (2007); Benton et al. (2002); Zhu and Chang (2008); Grinnell (1917); Karr et al. (2008); RRC (1999).

4.5 Historical Treatise on the Legacies of Invasion in India: Relation with the Wealth of Wildlife

In order to trace the reasons behind the spectacular legacy and elegance relating to the diversity of the wildlife in Indian scenario, an in-depth analysis of the turbulent history of India during last few centuries and the impacts of different components of complex assemblages of numerous Indian cultures and religions on the habitats, disturbed the wild life to spend a normal life. In the process of conquering the Indian subcontinent after being attracted by its rich natural resources, several powerful invaders had introduced their own culture as well as new religious beliefs to this part of the world. Although dearth of historical records before the Aryan invasion still exists, the Indian civilization is still claimed to be the world's oldest. It probably dates back to the middle of the third millennium **BC**, with the traces of existence of Paleolithic man and also the relics in the excavated sites of the Bronze Age cites of Harappa and Mohenjo-Daro in the Indus Valley, pointing the possibility of the presence of an agrarian Dravidian people, who probably migrated from the Iran during the period of **2500** and **1900 BC**. Their strange pictographic alphabet, drawings, sculptures, and figures depicting skillful craftsmanship showed the evidences of the existences of tigers, elephants, and one-horned rhinoceroses which lived in the valley of the Indus, the present form of which environment of those places represent only treeless desert.

With the massive invasion of the Aryans, Russia had occupied all of northern India by **600 BC** paving the way of evolving religions of Christ followed by the introduction of other religious teachings of Buddha and Mahavira. At the time of invasion of the Great Emperor Alexander in and around **327 BC**, the two extreme parts of India, the northern and southern parts, were ruled by the Mauryas and the king, Nanda, respectively. The religion Buddhism was spread throughout the length and breadth of India except some of the extreme regions of South India, after the establishment of the dynasty of Great Emperor Ashoka in **274 BC**. King Ashoka is still regarded as the world's first known conservationist, who first tried to promulgate the concept of protecting all wildlife by his fifth edict as inscribed on the stone pillars erected on the boundaries of his empire. Therefore, it is an established historical fact that a wide variety of forests with innumerable number of trees and their associated animals of the Indian subcontinent got proper protection since the ruling days of Great King Ashoka.

The Indian cultures and religions have had a chequered history because of the successive invasions by the Greeks, the Sakas, the Parthians, and the Kushans which resulted in the enrichment of Indian culture by inculcating so many good ingredients of different cultures with their languages, creative arts, and heritages. However, with the prevalence of dynastic rivalries during third century **AD** and following another four centuries, India had to succumb on the invasion thrust from the White Huns and the powerful Arab legions more and witnessed several fragmentations of her landscapes. The subsequent long Muslim dynasty spanned a period of **240** years (**1526–1761 AD)** by the several generations of the Mughal emperors, descendants of the Mongol Genghis Khan and successively represented by the emperors such as Babar, Humayun, Akbar, Jahangir, Shah Jahan, and Aurangzeb. Thereafter, India experienced the rulings of white western rulers mostly to promote their western trading enterprises. At the initial phase were the Portuguese, who gained control of the Malabar Coast; second were the Dutch followed by the British and the French, the Danes, and the Swedes. Through which another religion, Christianity was introduced in India. Consequently, India became the part of the British Empire in **1886** when Britain succeeded in excluding its competitors. India finally gained her independence in **1947** after the Second World War and proudly became a self-governing republic but at the cost of the emergence of Pakistan as a separate Muslim nation mostly because of the politically irreconcilability in between the peoples of Hindus and Muslim. In the year **1971**, the erstwhile East Pakistan was transformed into another independent Bangladesh.

Therefore, several religions got the chances to flourish during the earlier historical processes which can be ranked in accordance with their numerical order of importance as the Hindus, the Muslims, the Christians, the Sikhs, the Jains, the Buddhists, the Parsees, and the Iranians. The innumerable Hindu gods and demons in the religion of Hinduism are associated with varieties of wildlife and are worshipped at different times. Broadly speaking, they ensure reward for virtue in the next incarnation and punishment for ill-doing is one. The prime message of the religion Hinduism is not to harm any animal intentionally, as in the Hindu mythology, **God and nature** tend to remain as one and the animals like cow is regarded as sacred.

There is a considerable measure of animism in the more primitive forms of Hinduism. In the **Vedic religion**, **theology** of the **Hinduism** encompasses multidimensional aspects of nature through their own deities, for example, **Vayu** rules the wind, **Soma** the plants, **Garuda** the birds, **Jambavan** the bears, and so on. The configuration of god Ganesa with elephant head, many-headed cobra associated with the mythical **Nagas**, etc. highlights the involvement of wildlife in the Hindu religious activities. A strict Jain considers killing of living animals as sin. **Muslims** having no religious restrictions can become the skillful hunters. **The Hindus** and **Jains r**epresenting the great majority of the Indian population have undoubtedly been a major factor in maintaining the richness of Indian wildlife. During the period of **British rules**, social recognitions of hunters and profession of hunting were accorded which were reflected by those great hunting parties organized by the **Maharajahs** in honor of local or visiting dignitaries resulting in the slaughtering of an innumerable number of wild predators which are revealed from a number of books written mostly by soldiers and government officials.

Tigers had been hunted even before the Indo-Aryans arrived in the Indus Valley. The earlier Bronze Age Harappa civilization used the image of a "**tiger**" on its seal, and the first Mughals are known to have enjoyed "**tiger-hunting**." It became the sports of kings and remained so for more than a thousand years.

Example of such hunting program in the year **1919** accounted for the killing of **120** tigers, **27** leopards, and **18** sloth bears within a very few days. Many Englishman claimed to have shot **100** tigers during their tours of duty in India. A few hunters claimed as many as **300**, the record being held by the **Maharaja of Surguja**, who is on record as having declared that during his lifetime he had killed no fewer than **1150** of these animals. Many Maharajahs claimed their first tiger at the tender age of **12** and continued shooting them until well into their **70**s (Cubit and Mountfort 1985)**.**

Not until the late **1930s** was the first voice raised in defense of the tiger, when the great hunter-naturalist **Jim Corbett** published books expressing concern about their declining population. He prophesied, to the astonishment of many, that unless excessive hunting and the destruction of the forests could be curbed, the tiger would soon become extinct. Few believed him, because at that time he was thought that there were still at least **40,000** tigers in India, to say nothing of those in the adjacent countries.

However, instead of citing this hunting as the principal cause of such decline of wildlife, massive and progressive destruction of the forests where most of the animals keeping pace with several developmental phases under the rules of British, especially to meet the demand of railway industries coupled with the construction of several built wooden structure should also be considered as major reasons for the alarming loss of wild species. Meanwhile, the rapidly increasing human population, with ongoing demand for developing own land, have resulted in the exploitation of the previously protected forests, many of which had been owned by the now dispossessed Maharajahs. The effect on wildlife was devastating (Cubit and Mountfort 1985).

4.6 Colonialism as an Ecological Watershed

Despite the grave inequalities of caste and class, then, precolonial Indian society had a considerable degree of coherence and stability. Even the **Mughals**, whose religion was Islam, were unable, or perhaps unwilling, to radically alter the existing patterns of resource use and the social structures in which they were embedded. It was an entirely different story vis-à-vis India's contacts with **Christian Europe**. When this contact began in the sixteenth century, Europe was on the threshold of the momentous process of social change known as the Industrial Revolution. While the economic, political, and social changes that come in the wake of the Industrial Revolution have been the staple of scholarly work for decades, it is only now that the ecological implications of this process are being unraveled.

These three characteristics of the industrial mode of resource use are central to a proper understanding of the ecological encounter between India and Britain. For the elevation of the commercial over subsistence uses, the delegitimization of the community, and the abandoning of restrains on resource exploitation, all ran counter to the experience of the vast majority of the Indian population over which the British were to exercise their rule. This was a clash, in more ways than one, of cultures, of ways of life.

The ecological history of **British India** is of special interest in view of the intimate connection that recent research has established between western imperialism and environmental degradation. World ecology has been profoundly altered by western capitalism, in whose dynamic expansion other ecosystems were disrupted, first through trade and later by colonialism. Not only did such interventions virtually reshape the social, ecological, and demographic characteristics of the habitats they intruded upon; they also ensured that the ensuing changes would primarily benefit the **Europe**. Colonialism's most tangible outcome (one whose effects persist to this day) related to its global control of resources. The conquest of new areas meant that the **24** acres of land available to each **European** at the time of "**Columbus Voyage**" soon increased to **120** acres per **European**.

4.7 The Rich Wildlife Diversity in India: Interminglings with River Ecosystems

Only two major environments have remained physically unchanged over vast period of time, the jungle and the sea. Even here, the biological conditions have gradually altered as evolution, within or outside their frontiers, has produced new kinds of organisms and therefore presented their older inhabitants with new problems of survival. So almost every corner of the planet, from the highest to the lowest, the warmest to the coldest, and above to below water, has acquired its population of interdependent plants and animals. It is the nature of these adaptations to have enabled living organisms to spread so widely through the ecozones of the mother earth.

The wildlife of the Indian subcontinent command the global attention and recognition because of the diversity of species along with their diversified forms of habitats located at widely varying agroclimatic conditions of different biogeographic provinces. India is the house of about more than **400** different species of mammals, **2000** species of birds, and hundreds of reptiles and amphibians. The wildlife of India are more special and very difficult to locate as most of the larger wild fauna prefer to hide in the deep forest mainly displaying nocturnal or at best crepuscular behavior in contrast to the wildlife of Africa, where they inhabit mostly in open savanna.

Besides, after the independence of India in the year **1947**, law and orders were found to have been broken down leading to a turmoil condition absorbing the shocks of partition of the erstwhile India into two separate countries; the newer one is named as Pakistan, and this changed situation had paved the ways of the universality of hunting with the involvement of rural peoples who got the access not only to fire weapons but also to the previously protected forests and hunting reserves. Different wild charismatic species including tigers, elephants, bisons, etc. were shot, trapped, and poisoned, and the body parts (skins, bones, nails, horns. etc.) of which were sold in the simultaneously developed black markets for trading, and this system was continued for several years before these practices were brought under control. The rural folk are the custodians of our wildlife. Leaving aside sentiments and aesthetic considerations, let us consider the ways in which wildlife in and around the human settlements, especially the village areas, become valuable allies in **the** material advancement of human civilization (**Tables 4.2, 4.3, and 4.5).**

4.8 Diversity of Landscapes, Habitats, and Wildlife (Flora and Fauna)

4.8.1 Wildlife of India: Ecological Interpretation

To a common man, the term wildlife means the wild undomesticated animals living in their natural habitats as forests, deserts, grasslands, etc., but ecological interpretations include both the naturally occurring animals (fauna) and plants (flora) in wildlife and their occurrences, propagation, intraspecies and interspecies interactions, behavioral activities, and distribution in respect of their intimate relationships with the habitats experiencing distinct climatic conditions. Such interactions among different groups of wildlife develop a pyramid mostly based on prey–predator relationships among several other relationships where the apex is occupied by big cats, and the intermediate levels above the herbivorous base are formed by lesser carnivores, small predators, and scavengers. The attacks of predators are triggered by the increasing numbers of the preys, whereas the availability of grass belts impose limits for the flourishing of herbivores whose numbers in turn limit the abundance of carnivores.

4.8.2 Ecological Roles of Wild Animals in India

Wildlife, being the integral part of the river–forest ecosystems, play vital roles in maintaining ecological balance facilitating the development of interlinkages among the biotic and abiotic components through a steady and continuous trophic interactions, biogeochemical cycles, and positive and negative feedback systems. Disappearance or extinction of any species from the biotic (wildlife) community disrupts the normal ecological functioning (energy flows and decomposition cycles) and through a chain of adverse ecological consequences impose severe adverse ecological threats to the life of other species. As a result of the disturbances in the natural balance, the riverine ecosystem along with their riparian forests becomes vulnerable to experience the loss of species which often results in unfavorable and undesirable outcomes that ultimately affect mankind.

Not far behind, maybe around **300** years back, the different forest tracts in India accommodating diversified form of ecosystems such as tropical deciduous and temperate coniferous grasslands, deserts, mangroves, flood plain riparian forests, etc. were inhabited by innumerable number of wild fauna represented by mammals, birds, reptiles, and amphibians, and plenty of fishes which had their population in water bodies. All these animals had had intense interactions among themselves and with other structural components of their respective ecosystems playing effective roles in maintaining the biogeochemical, successional, prey–predator population dynamics and other ecological processes that were functional and persisted for centuries. By virtue of their different forms of behavioral manifestations, feeding strategies, viz., herbivory and predation and ability to cause physical disturbances, wild animals have been found to alter the patterns of food supply, change in the duration and biological attributes of life cycles, modify species composition within biotic community, and induce development of physical and chemical defense mechanisms.

Wildlife by virtue of their ecological roles also serve many ecological services for the direct benefit of the human beings. Birds along with several others volant (Chiroptera) and arborial (squirrels) serve as pollinating agents, assist in fruit and seed dispersion, eat a large number of harmful insects and other pests, as well as play the vital roles as scavengers in many ecosystems. Snakes by controlling the rodents help in the higher productivity of the agriculture, whereas elephants by destabilizing forest trees help in allochthonous nutrient generation and make scopes for other herbivores to get foods and also releasing a huge amount of dungs recharge the soil fertility. Peoples residing within the vicinity of forests harvest so many forest plant-based products in the form of non-timber forest produce (**NTFP**) in the form of fire wood, medicinal plants, different types of fruits and seeds, natural rubber, gums, resins, tannins, essential oils, etc. and also animal products like honey, silk cocoons, horns, ivory, fur, etc. However, hunting of wildlife and trade in wildlife parts is strictly prohibited under the **Wildlife (Protection) Act of 1972** in India. Besides, wildlife sanctuaries and national parks have become an important source of the popularization and development of ecotourisms, based on which livelihoods of so many local peoples are maintained on one hand and pave the way of collection of government revenues on the other.

4.9 Past and Present of the Ecological Subregions in India: Global Perspectives

4.9.1 Global Scenario of the Forest Distribution

4.9.1.1 Old World vs New World

The entire world is divided into two broad categories so far as the types, composition, age of formation, and geographical distribution into Old World and New World. Both terms have great significance and are particularly meaningful in the historical context. The terms are used not only to distinguish the major ecozones of the world but also to classify animal and plant species that were originated from the two worlds. Old World refers to a part of the world that was known to the human beings much before the Americans are acquainted with it. On the other hand, the New World being inclusive of North America belongs only to the Americas, including South America and Central America. In contrast, Old World refers to the Africa, Asia, and Europe and refers to that part of the world which was known to its citizens before it came into contact with the America.

4.9.1.2 Geographical Context of Forest Distribution

The New World ecozones range from the mossy tundra and vast coniferous forests of the frozen North America to the arid, tropical, southern border of Mexico in South America. In between these extremities, the rocky belts with prairies and forests extend up to the east and the Pacific coast to the west. Besides, grassy plains, the rugged Andes mountains, the ice-capped cold plateaus of Patagonia, and the Amazon basin with the world's largest tropical rain forest represent ecozones of the South and Central America. The New World is separated by the vivid presence of the Atlantic Ocean from the Old World, where Europe and North Asia enjoy a continuous stretch of coniferous forests of Scandinavian and Siberian regions in the north to the mountainous forest belts of Southern Europe, and also from the British Isles, a group of islands in the North Atlantic off the northwestern coast of continental Europe to the islands of Japan in the far east. The Old World also includes mountains with their forest coverage of Central Asia, the Himalayas, the Tibetan Plateau of South Asia, and the monsoon lands of India and Southeast Asia. The splitting from the cleft of the Red Sea forms the Africa, characterized by having grasslands (the Serengeti), teeming with wildlife at the East and South Africa and rain forests at the West and Central Africa. The northern Africa has been dominated by the harsh Sahara at the North and Hawaii, in the Pacific Islands, and has some unusual plant life. Australasia, a world apart, consists of Australia (with its unique pouched animals), New Zealand, and New Guinea with some specialized forms of wildlife (oldest forms of plants and indigenous bats and birds like kiwi, kea, penguin, etc.).

4.9.1.3 Biological Context of Forest Distribution

In the biological context, New World and Old World are often quoted for citing species of plants and animals. The Old World species fall under two categories, namely, Afrotropic and Palearctic. On the other hand, New World species are grouped as Neotropic and Nearctic. In addition, all species that are found exclusively in the Americas are considered as New World species. The forest that occurs in the Old World is also known as primary forest, virgin forest, or forest primeval. They are characterized in attaining a great age without significant disturbances and thereby exhibit unique ecological features as good as a climax community. Besides, so many tree-related structures are manifested by the old-growth forests providing shelters for diverse wildlife and thereby increase the biodiversity of the forested ecosystem. The diversity of tree structure promotes the development of multilayered canopies and canopy gaps, which distinctly vary with the heights and diameters of the trees and diverse tree species. This kind of forests is valuable for economic reasons and for the ecosystem services (maintenance of biodiversity, water purification, flood control, and nutrient cycling) they provide. The Old World forests often contain rich communities of plants and animals within several types of habitats due to long period of forest stability. These varied types and sometimes rare species may depend on the unique environmental conditions created by these forests.

4.10 Ecological Past of the Wildlife Habitats in Asia

4.10.1 Geological Past and Development of Ecological Passage

Separated from the landmass of northern Asia by the greatest range of mountains in the world, the Indian subcontinent forms a giant triangular pendant washed by the warm tropical seas of the Indian Ocean. Only two relatively narrow corridors provide passage ways for land animals to and from the subcontinent: the desert between the foothills of the Hindu Kush and the Arabian Sea to the west and the flood plains and delta of the Ganges-Brahmaputra river system to the east (The Atlas of world wildlife, 1973). Around **10** million years ago, India, not being a part of Asia, remained as an island continent edging slowly northwards towards Asia across a vanishing ocean (Tethys, on the Mediterranean, Black and Caspian seas) by the presence of which Africa remained isolated from Eurasia. About **15** million years back, India moved up against the southern coast of Asia, the impact forcing a crumpling of most of the unconsolidated landmass into the towering Himalayas. At the same time, Africa came very close to Europe, and three landmasses, namely, Africa, Eurasia, and India, became fused together causing tremendous interchanges and reshufflings of faunal components among the three. Several wild fauna such as civets and dogs, rhinos and giraffes, ancestors of African baboons, and guenon monkeys started moving towards Africa from the west. Animal assemblages of the moist deciduous forest on the west coast of India show close resemblances to the forest animals of Malaya and Indochina because of the development of tropical forest connections between these areas during that period. Other species started moving eastwards into India through the northwestern desert, such as the gazelle and jackal, which are very much identical to the same that were found in Africa and Near East. The wild boar, an adaptable species, occurs throughout the Eurasia, including India, and the tiger started spreading south from the chill Siberia, invading India from the east in quite recent times. The Asiatic lions, which arrived from the west, survives only in the forest of Gir reserve.

4.10.2 The Early Onslaught on Forests in India

By around **1860**, Britain had emerged as the world's leader in deforestation, devastating its own woods and the forests of Ireland, South Africa, and Northeastern USA to draw timber for shipbuilding, iron-smelting, and farming. Upon occasion, the destruction of forests was used by the British to symbolize political victory. Their early treatment of the Indian forests also reinforces the claim that "the destructive energy of the British race all over the world" was rapidly converting forests into deserts (Webber 1902). Until the later decades of the nineteenth century, the Raj carried out a "fierce onslaught" on the subcontinents' forests (Smytheies 1925).

4.11 Ecological Subregions in India: Forests and Climate of India

India's unique climate and landscape support typical animals in each region. India and its neighbors constitute a unique subcontinent. Though it is in the tropics, it differs in climate from all other countries of this belt, because it has an exclusive monsoon climate. The forests of the Indian subcontinent, from the Himalayas to the Andaman, range from the tropical, and moist evergreens here are deciduous trees. The evergreens here are broadleaved and do not have conifers. These evergreen forests indicate almost **80** inches (**200 cm**) of rainfall in the area, whereas the deciduous forests indicate definite wet and dry seasons. In the latter type of forests, what is striking is that all the animals and birds are smaller since the temperatures are higher. Different ecological zones of India are as follows**:**

1. **Himalayan mountain system**: There are altitudinal as well as east–west variations in this region. There are three distinct sub-zones each with its characteristics fauna and flora:

   (a) **Himalayan foothills**: These extend from the eastern frontiers of Kashmir to Assam.
   (b) **Western Himalayas**: It includes higher altitudes in the Himalayas from Kashmir including Ladakh to Kumaon.
   (c) **Eastern Himalayas:** It includes regions of Sikkim and extends in the east up to NEFA.

2. **Peninsular India subregion**: This is the raised plateau land of the Deccan extending into the flood plains of the Indo-Gangetic Basin westwards into the Great Thar Desert of Rajasthan.
3. **Tropical evergreen forests or Indo-Malayan subregion**: This is the region of heavy rainfall comprising northeastern India and Western Ghats in south including Malabar Coast. Only two major environments have remained physically unchanged over the vast period of time – the jungle and the sea. Even here, the biological conditions have gradually altered as evolution, within or outside their frontiers, have produced new kinds of organisms, and therefore have presented their older inhabitants with new problems of survival. There are large areas of unspoiled tropical wet evergreen forest with luxuriant and impenetrable cane thickets, creeping bamboos, lush green carpets of scrubland and grasslands, and flowering epiphytes. The riparian forests along river banks intermingle with immense hanging curtains of different creepers hang from the trees, overlapping a variety of herbs and shrubs reflected by the blossoms of their flowers attracting a swarm of different birds such as colorful sunbirds, tailorbirds, munia, bee-eaters, drongos, myna flower-peckers, etc. The abundant fruits of the climbing creepers are constantly consumed by various species of squirrels, lizards, monkeys, bears, and different birds. So almost every corner of the planet, from the highest to the lowest, the warmest to the coldest, and above to below water, has acquired its population of interdependent plants and animals and nature specific have enabled living organisms to spread so widely in the varied ecosystems across the world.

Both vegetation and animal life in India are largely governed by the incidence of the monsoon. Many fruit-producing trees, climbers, and crops provide fruits in the year synchronizing with the monsoon cycle. The migration and nesting of most of the frugivorous wild fauna also conform, so that advantage can be taken of the explosive abundance of insect life and fresh vegetation that follows. The vegetation of the subcontinent is divided into **16** major types of forest ranging from tropical evergreen and moist deciduous to dry temperate, tidal, and alpine. Each of these green communities supports the lives of distinctive communities of dependent wildlife, after being governed by the power and vagaries of the monsoon.

4.12 Cosmopolitan Distribution of Forests Along with Wild Fauna

4.12.1 National vs International Distributional Patterns

Many of the tropical and subtropical and woodland regions are roamed by wildlife which have their European counterparts in the forest regions of the countries of the Western Mediterranean. It is not unusual to encounter an equivalent wealth of wildlife. Animals living together are normally regarded as belonging to entirely different biomes. A number of typical carnivores of the Palearctic region, such as foxes, weasels, martens, bears, and lynxes, are found to inhabit in the Oriental regions and other forest hunters of the Asian subcontinent including the panther (*Panthera pardus*), the leopard cat (*Felis bengalensis*), and the Himalayan black bear (*Selenarctos thibetanus laniger*) as the ancient inhabitants of these forests have been spreading into the Central Europe. These predators hunt a wide range of familiar animals, including red deer, roe deer, elks, squirrels, mice, and shrews, as well as localized species such as the goral (*Nemorhaedus goral*), a sika deer (*Cervus nippon*), the short-eared Chinese hare (*Lepus sinensis*), and the lives of other small mammals and birds have been equally remarkable.

4.12.2 Wild Fauna of Indian Subcontinent

The natural history of the Indian subcontinent along with its rich diversity of biological wealth still remains mysterious and fascinating along with the incomparable diversity of ecosystems which have been created through a series of geological events spanning a period of millions of years.

The northern part of India is characterized by the presence of the magnificent Himalayas with her luxuriant green coverage supporting the lives of some rare and evasive wild fauna such as snow leopard, musk deer, ibex, pheasants, etc. Besides, the plains of the northern part of India accommodating Jim Corbett National Park and Dudhwa National Park harbor some majestic and charismatic species such as tigers, leopards, Asiatic black deers, gharials, and different species of deers in the large chunks of tropical mixed deciduous forests, mainly dominated by the sal tree (*Shorea robusta*) and segun (teak (*Tectona grandis*)) tree.

The western part of India having the Great Indian Desert, named as the Thar, spreading between India and neighboring country Pakistan, represents a unique ecozone having a variety of hardy thorny plants and some wild animals (wild ass), not encountered in other parts of the world.

The eastern part of India, bordering the neighboring countries like Bhutan, Bangladesh, and Burma, includes varied forms of forests (tropical deciduous, temperate coniferous, verdant grasslands and coastal mangroves) in the foothills of the Himalayas and the floodplains of the Indus, Ganges, and Brahmaputra rivers and provides shelter in different forms of wild fauna life ranging from large herbivores (elephants, rhinos, Gaurs, etc.) to efficient carnivores (tigers, leopards, hyenas, jackals, wolves, etc.).

The southern part of India, which accommodates an ancient chain of hills running from north to south through biodiversity enriched the Western Ghats of the Himalayas and biologically productive western coast of India, besides supporting the Asia's densest rain forests.

4.12.3 Ecological Uniqueness of Tropical Asia: Wildlife Wealth

Southeast Asia harbors varied forms of wild plants, both exotic and indigenous, which support a plenty of wild animals which can be compared with any part of the globe, even with the wildlife diversity of Africa. However, this huge geographical block of Asia with its biological wealth has remarkably suffered from the lack of ecological knowledge substantiated by reliable research information of biological components of several eco-regions. It is an established fact that no area of the world is more richly endowed with forms of life than tropical Asia along with its widely scattered archipelagoes of neighboring islands which are endowed by the grand design of the nature with such diversity of wildlife that outcompete the rest of the world.

The plains of India eastwards through the Indo-Chinese Peninsula and along all the outlying offshoots of the Malay Archipelago represents a unique landscape characterized by its proliferation of species. **Alfred Russel Wallace**, the great naturalist who coincidentally with **Charles Darwin** proponent of the theory of evolution by natural selection, found his chief source of inspiration from several ecozones of this subcontinent and was moved to describe the wealth of islands in memorable words: "**Bathed by the tepid water of the great tropical oceans, this region enjoys a climate more uniformly hot and moist than allmost any other part of the globe, and teems with natural productions which are elsewhere unknown**."

This part of the Oriental region zoogeographically includes the Peninsula of India on reaching to the north of the Himalayas and south to the Ceylon and then further moving to the east through Pakistan and the Andaman and Nicobar Islands to Burma, Thailand, and the Indo-Chinese Peninsula. Further, the islands of Indonesia are with Lesser Sunda Islands, the Moluccas, and finally the Philippines at the east. All these geographical units form the tropical region which combines elements of a very ancient world with elements of a modern world which has been undergoing active stages of building-up process. The Oriental region with its western part rests on an old and permanent continental foundation in India, whereas much of the southeastern part still is an area of great instability experiencing eruptive volcanoes and islands rising out of the sea surface. Although great changes occurred throughout geological time, the vertebrate fauna of the Oriental region are supposed to have been evolved and distributed during the Pleistocene era in the geological time scale (last million or so years of the earth's history) when the most important geological events driving and shaping this development took place.

A number of major cycles of alternating cold and warm climates in the more northern latitudes during the ice ages resulted in the dropping of the level of the seas to the extent which in turn triggers the emergence and stabilization of connections among the islands of the Sunda Shelf. The simultaneous falls and rises of the sea at various times connected much of the Malay Archipelago with the mainland and after again encounter the fragmentations of the connections among the thousands of islands once again. Such unpredictable and erratic geophysical events in a sequence of continuity and discontinuity had disturbed and complicated the patterns of movement of all kind of animals into and through the southern part of the area.

Most of these, furthermore, occurred after the evolution of the highest mammals; such ups and downs of the sea levels acted as the hindrance on the natural evolutionary pathways of many species, including the higher primates like orangutan and man. These kings of natural forces resulting in geological changes gained momentum in the tropical Asia where higher amount and intensity of rains aggravated the ecological condition by generating erosive torrent that loosens soil from the mountain sides and feeds it to swollen rivers.

Moreover, natural process during floods with sediment-loaded turbid water, counteracting resistance or friction from any substances such as riparian forests or even moving water from the opposite direction, accelerates the process of sediment deposition on the newly formed delta, or continuous dumping of sediment at the confluence of river and sea resulting to the development of new delta. Besides on the islands, volcanoes bury old contours under layers of ash, while streams of lava create new landforms. Rain and heat work together making tropical Asia as one of the biodiversity enriched regions in the world, characterized by the luxuriant growth of vegetation enjoying heaviest rainfalls and even developing rain forest where a wet season is followed by a rainless one. The forest becomes leafless and barren during the dry months, where it again rejuvenates with the rhythm of life with the onset of the rains, bursting into bloom and growing lush and thick.

4.13 Behavioral Ecology of Wildlife: Implications in Conservation Biology

4.13.1 Social Organization of Wildlife and Underlying Survival Strategies

Many animals live in aggregations or groups consisting of several individuals of a species. Such groups may be called animal societies in analogy with human societies. The interaction between individuals in such animal societies is referred to as social behavior. In recent times, the study of social behavior in animals has become a very popular new science called sociobiology. The aim of sociobiology is to understand the forces that bring animals together and that shape the form of social behavior. Animals present a large variety of social system to permit such an analysis. A survey of the animal kingdom reveals varying degrees of social behavior. Edward O. Wilson has recognized colonial invertebrates, social insects, nonhuman mammals, and human beings as the four pinnacles of social evolution. Among the colonial invertebrates, the myxobacteria, the slime molds, siphonophores, and corals may be included. In myxobacteria and slime molds, there is a free swimming phase when individual bacteria or amoebae lead what can be termed a solitary life. Under certain conditions that are suggestive of deterioration of the habitat (such as starvation, lack of some crucial amino acids, etc.), the solitary individuals come together.

The hypothesis that haplodiploidy has been a key factor in the evolution of hymenopteran socially has an additional virtue in that it leads to a number of predictions that have been largely borne out by observations on the colonies of social insects, for example:

- **(i)** Eusociality should be more common among haplodiploid organisms than among others.
- **(ii)** Males should be more selfish than females.
- **(iii)** Females should be more altruistic in their behavior towards their sisters than towards their brothers.
- **(iv)** Workers should favor their own sons over their brothers.

It must be cautioned that a number of ecological factors favoring colonial over solitary existence must be operating hand in hand with haplodiploidy generate the extreme degrees of social organization and altruism witnessed in the hymenoptera. The involvement of such other ecological factors is the reason that a number of haplodiploid species have not attained eusociality and that the diploid termites have done so.

A group of animals that are considered to not have any elaborate social organization are the cold-blooded vertebrates comprising fishes, amphibians, and reptiles. It is very likely that this notion is primarily by virtue of our ignorance regarding several aspects of the life of these animals. More recent studies appear to give the impression that schooling in fishes, territoriality, and mating systems particularly of frogs and lizards are not far behind those of birds and mammals in their respective habitats.

4.13.2 Communications and Signaling: Adaptive Strategies

Communication can be explained as mutual exchange of messages, known as signals in between two individuals of one or different species, aided by the specially evolved traits specified for different sensory modalities. The signals are transferred by the senders to the receivers with the aim at reorienting their behaviors to gain more benefits and productive outcomes on getting the feedback reactions from the receiver. Similarly, the receiver responds to the signal in such a way so that the possibility of having beneficial effect for both the senders and receivers increases. Though, the signals are often beneficial to both the senders and receivers, but the sender primarily provides the information in an attempt to manipulate a receiver's behavior to its own advantage. Such exchange of signals plays vital roles in detecting the location of preys or predators to ensure successful mating or breeding by locating and also attracting the individuals of opposite sexes. Exchange of information through signaling among different individuals or species occurs with the help of olfactory and visual sense organs, by the pheromones (species-specific chemical messengers) and also by the mechanoreceptors with the tactile organs to ensure close physical contacts and even for the exchange of emotional feelings. In addition, acoustic signals play very effective roles in exchanging signals using the different pitches of sounds which create different levels of vibrations having varied frequencies of wavelengths (low pitch to high pitch, different intensity of loudness and periodicity).

4.13.3 Ecophysiological Adaptation and Adjustment for Social Organization

The physiological responsiveness, social organization, cognitive capacities, and life strategies of different wildlife species of different ages and genders even within the same species respond to and tolerate against environmental changes for the survivability of both individuals and species demonstrating their ability to locate, consume, and process adequate food, shelter, and successful breeding to perpetuate the species. Locating and harvesting of food with appropriate foraging strategies involves the use of special senses and postcranial musculoskeletal system in locomotor aspects of positional behavior and also manifesting postural behavior activities associated with oral movements for processing and mechanically breaking down of food in the mouth and chemically digestion and assimilation within the gastrointestinal tract. These three crucial facets of behavior enable the wild animals to cope up with the natural or human-induced changes of the environments.

Primates are unusual among mammals in their lack of anatomical specialization and in their behavioral flexibility. Their success lies in avoiding and in escaping the reproductive constraints of the estrous cycle. Although the behavioral, especially social, advantages of the menstrual cycle of haplorhine primates (tarsiers, monkeys, apes, and humans) are of prime importance, the focus in this chapter is on diet and feeding behavior in the widest sense – on the ecological aspects of behavior.

Most orders of mammals are specialized for faunivory (eating animal matters – vertebrate and/or invertebrate) or folivory (foliage specializations – eating leaves or grasses). In general, faunivores include the Insectivora (insectivores), Carnivora (carnivores), and Cetacea (whales and dolphins), whereas folivores include the

Rodentia (rodents), Proboscidea (elephants), Sirenia (manatees and dugongs), Perissodactyla (odd-toed ungulates), and Artiodactyle (even-toed ungulates). Only the Chiroptera (bats) being a nocturnal and arboreal mammals are tuned with a diversity of diets and consume insects, fish, amphibians, reptiles, birds, mammals, fruit, pollen, and nectar (Wilson, 1975, Debata et al., 2020). Specializations for chasing, capturing, and eating animals and animal-derived matters have not only developed but refined special sense organs for detection, i.e., the ability of sprinting both on land and in water so that chasing and capturing preys with powerful mandibles in the jaws for holding and strong teeth for puncturing, crushing, and shearing becomes possible. These wild fauna are also endowed with the elaborated and elongated small intestine, instead of the stomach or colon to digest these nutritious rare and elusive foods because of their mobility even after swallowing.

In contrast, herbivorous animals have specialized for leaf-eating center on large body size to accommodate adequate guts for the bacterial fermentation of foliage (either in an expanded sac of the fore stomach or in an expanded tube of the caecum and colon). The musculoskeletal system and special senses of folivorous animals have been organized to make the animals able to undertake to travel long distances in search of food and to sustain running away from sprinting predators once detected. The development of large-sized and complex dentition having specialized oral rearrangement of teeth with in the concomitantly increased in large sized jaws and skull added more efficiency in predating the preys. This category of animals reflects their hardworking ability to cut, chew, and masticate plant food materials and also to enhance the surface area for higher bacterial action.

In the process of adaptive radiation from an insectivorous, nocturnal ancestor, most of the small-sized mammals have preferred to experience frugivory living mainly on the reproductive parts of plants and then to switching over to the mode of feeding as folivory, eating on the abundant vegetative parts of plants in tune with varying degrees of further increases in their body sizes. This radiation has been achieved by the arboreal abilities (in posture and locomotion) with moderate body size enabling to ascend into most parts of the "**trophic tree**," abundant vegetative parts of plants and diversity of diet, evolving a morphology intermediate in most respects to the specialist faunivores and folivores (Ripley, 1979, 1984, Chivers 1984, 1998, 2001).

4.13.4 Special Senses for Behavioral Advantages

Increased socialization and behavioral flexibility in accordance with complex behavioral strategies of wildlife are provided by unique power of vision (stereoscopic) and vocal communication skills and controlled by the special sensory parts of the brain. Such behavioral acquisitions in conjunction with refined intelligence and enhanced manipulative skills have enabled to emit complex and graded signals (Nicolson, 1987; Ward et al, 2008). The poor power of vision is sometimes compensated by maximizing the stimulation of rods on the tapetum lucidum (the reflective layer behind the retina) in the eye and thereby enhances the visual ability.

4.14 Wildlife of India Having Dependence on Riparian Ecosystem

The incredible diversity and colors of nature's realm are vividly portrayed by the world's charismatic, elusive, and secretive animals. The wildlife of the Indian subcontinent emphasizes the diversity of species in widely different habitats and climatic zones. There are about **500** different mammals, more than **2000** species of birds, and several hundreds of birds, reptiles, and amphibians.

Out of the most incredible array of wildlife, mammals are the most charismatic of all faunas. Nearly about **400** species constitute the mammalian faunal diversity of India of which **146** have been identified as threatened species (Tikadar 1983). The mammals after first appearing in the earth in the Mesozoic Era about **181–135** million years ago have diversified from the rat-sized four-toed predators to huge-sized herbivores, long-fanged carnivores, and long-armed primates through the Cenozoic Era, into the "**Age of Mammals**," some **63** million years back. A number of the mammalian species are internationally acclaimed as the most attractive animal species of the world such as India's national animal, the tiger, which is not only enigmatic but evolutionary very unique. Around **65 percent** of the world's wild tigers and Asian elephants are found in India, as are **85 percent** of one-horned rhinoceroses. The Asiatic lion is only found in India. Besides, India is gifted with a number of antelopes and deers, and it has **5** species of big cats, **4** massive species of wild cattle, **11** species of wild goat and sheep, at least **12** species of primates, and numerous bats, rodents, and cetaceans. Herds of elephants at the several forest tracts of southern and northeastern India, swarming of bats in the derelict hill ranges and the caves, the mutualistic relationship among deers and monkeys in the forests of central India, and associations of wild goat and sheep who shift their altitudinal range in response to the climate offer unforgettable glimpses into the world of mammals (Gee 1964; Tikadar 1983; Alfred et al. 1998).

4.14.1 Class Mammalia and Its Faunal Wealth: Indian Scenario (Figs. 4.1, 4.2, 4.3, 4.4, 4.5, 4.6, 4.7, 4.8, 4.9, 4.10, 4.11, 4.12, 4.13, 4.14, 4.15, 4.16, 4.17 and 4.18, Tables 4.1, 4.6, 4.2, and 4.3)

4.14.1.1 Characteristics and Distribution of Mammals: A Generalized Approach

The human being, together with most of their domestic animals, and their wild counterparts belong to the class of animals, known as mammals. Members of the group range in size from the gigantic blue whale, the largest animal ever known on earth, weighing up to **120 tons**, to the tiny tree shrews having the length not exceeding an inch and weight of about **3** grams. Mammals, the most familiar

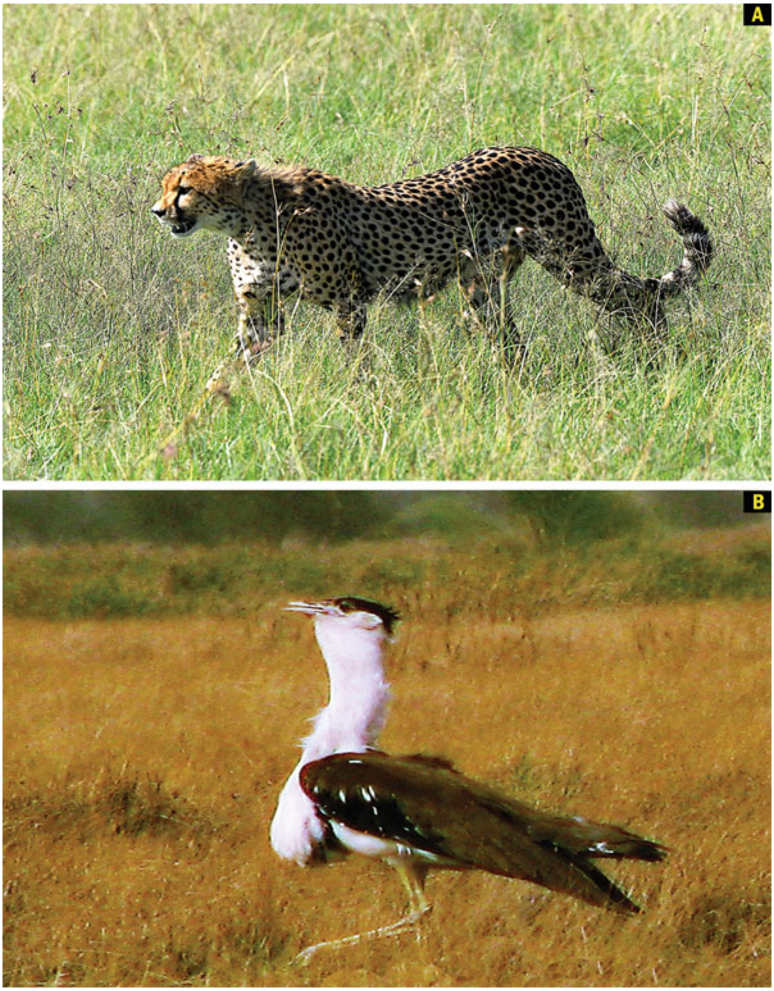

Fig. 4.1 Extinct and critically endangered species in India
(**A**) Cheetah (*Acinonyx jubatus*)
(**B**) Great Indian bustard (*Ardeotis nigriceps*)

group of vertebrates, all nourish their youngs on the milk produced by the female mammary glands; give birth to living offsprings, with hairs on the body covering; and are able to maintain constant body temperature. Mammals are found all over the world – polar bears and artic foxes have been found close to the North Pole, while whales, seals, and dolphins are adapted to life in the cold oceans. Generally regarded as the most advanced animals, mammals are craniates; that is, they have skulls and backbones but differ from the amphibians, reptiles, and birds, by possessing a larger brain, hairy skin, and an ability to suckle their young. They are warm-blooded homoeothermic animals with four chambered heart with left aortic arches. More than

Fig. 4.2 Nonhuman primates (Langurs and Phayre's leaf monkey) found in India excepting vervet and langur
(**A**) Southwestern langur (*Semnopithecus hypoleucos*)
(**B**) Hanuman langur (*Semnopithecus entellus*)
(**C**) Phayre's leaf monkey (*Trachypithecus phayrei)*
(**D**) Female capped langur or leaf monkey (*Trachypithecus phayrei pileatus*)
(**E**) Male capped langur or leaf monkey (*Trachypithecus phayrei pileatus*)
(**F**) Golden langur (*Semnopithecus geei*)
(**G**) Kashmir or Chamba langur (*Semnopithecus ajax*)
(**H**) Vervet langur of Old World (*Chlorocebus pygerythrus*)

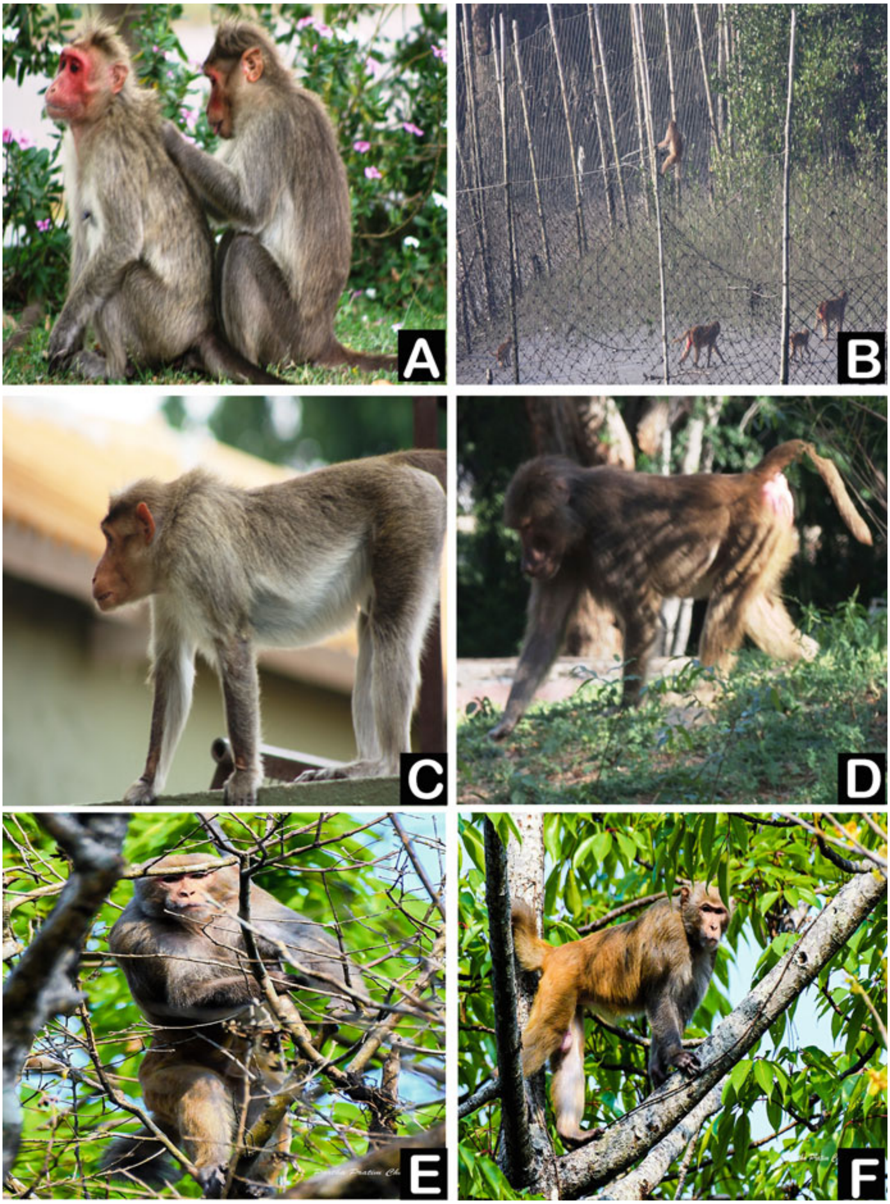

Fig. 4.3 Different species of macaque monkeys found in India
(**A**) Different species of rhesus macaque (*Macaca mulatta*)
(**B**) Rhesus macaque (*Macaca mulatta*): playing in group with fishing nets erected by local fishermen
(**C**) Male bonnet macaque (*Macaca radiata*)
(**D**) Female bonnet macaque (*Macaca radiata*)
(**E**) Male Assamese macaque (*Macaca assamensis*)
(**F**) Female Assamese macaque (*Macaca assamensis*)

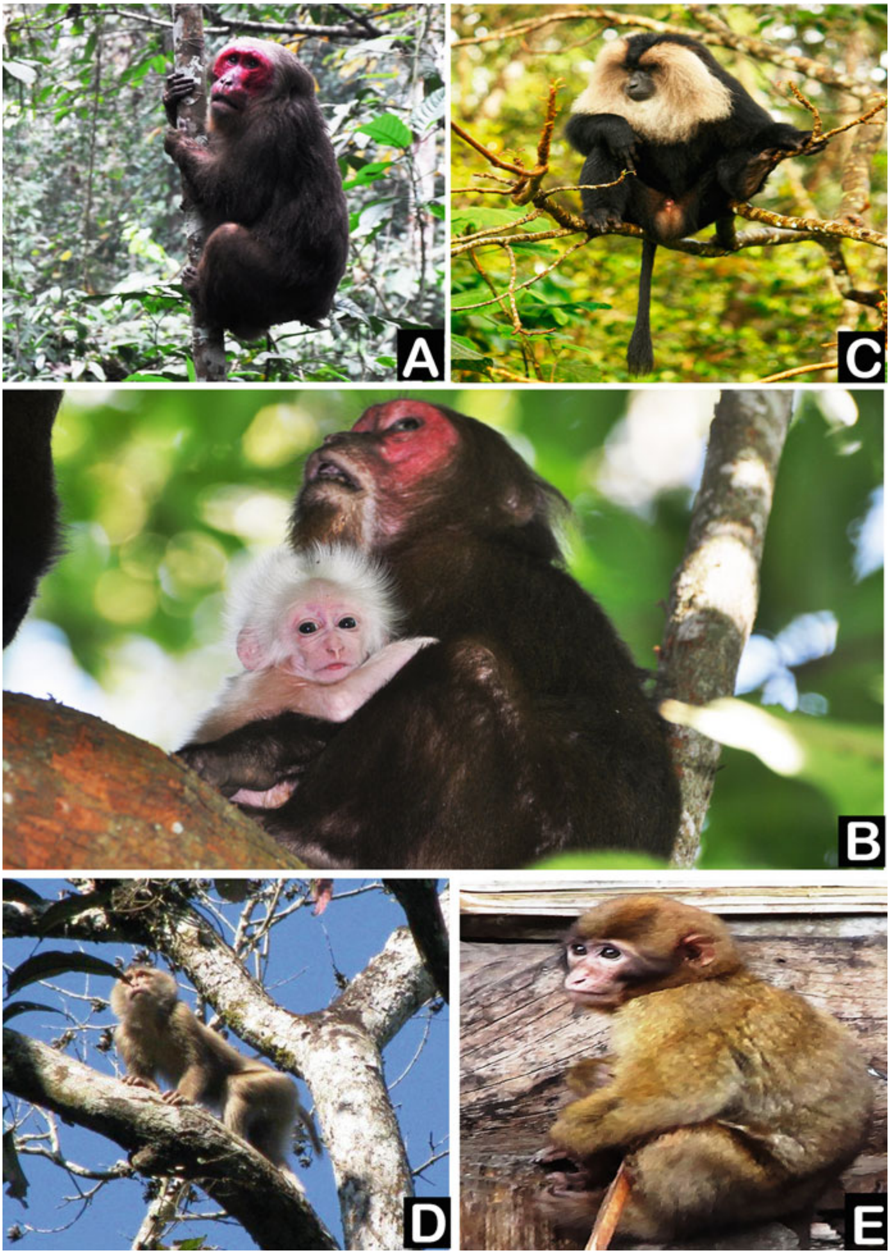

Fig. 4.4 Different other unique species of macaque monkeys with restricted distribution in India
(**A**) Male stump-tailed macaque with infant (*Macaca arctoides*)
(**B**) Female stump-tailed macaque (*Macaca arctoides*)
(**C**) Lion-tailed macaque (*Macaca silenus*)
(**D**) Pigtailed macaque (*Macaca nemestrina leonina*)
(**E**) White-cheeked macaque (*Macaca leucogenys*)

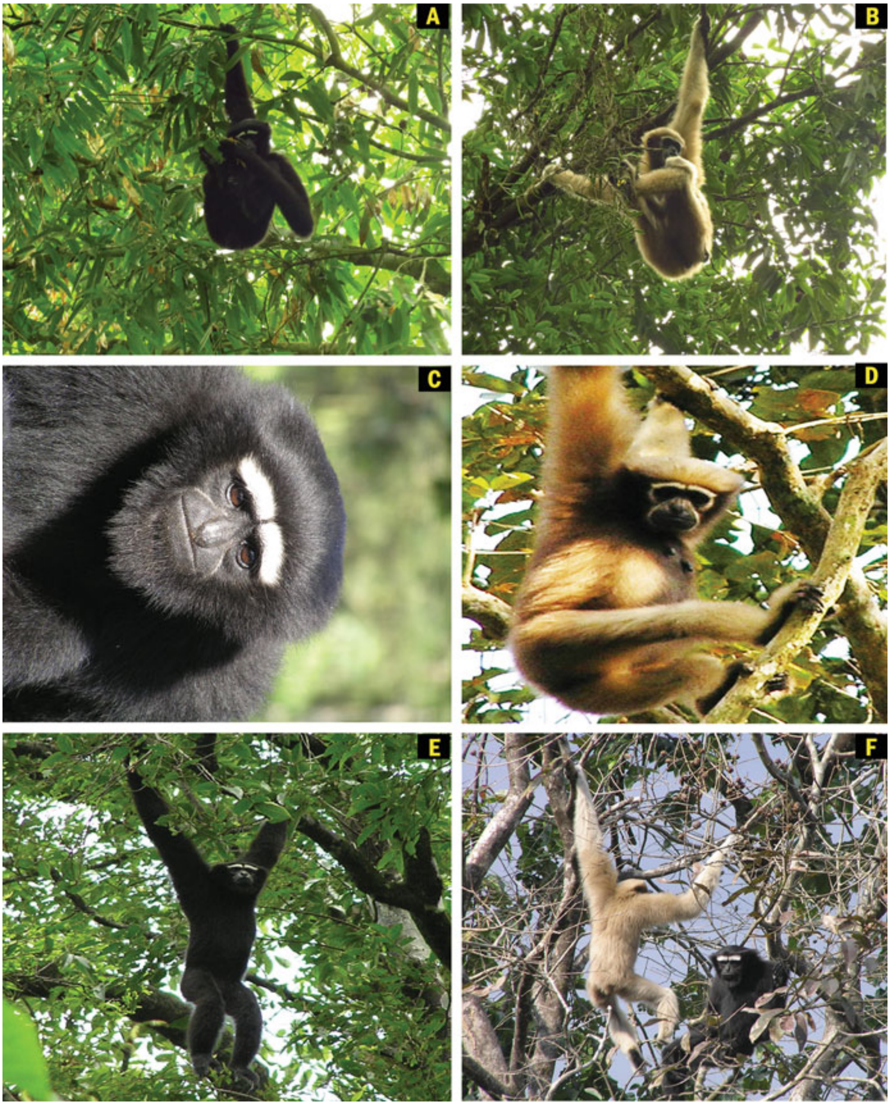

Fig. 4.5 Two representative species of hoolock gibbons (western and eastern)
(**A**) Male eastern gibbon (*Hylobates leuconedys)*
(**B**) Female eastern gibbon (*Hylobates leuconedys)*
(**C**) Male western gibbon (*Hoolock hoolock*) in relaxed mood
(**D**) Female western gibbon (*Hoolock hoolock*) in resting mood on the branches of large tree
(**E**) Male western gibbon (*Hoolock hoolock*) in his movement posture
(**F**) Female and male western gibbon (*Hoolock hoolock*) in courtship movement posture

8500 species of mammals are at present alive on the earth (Gee 1964; Tikader, 1983; Ellermanand Morrison-Scott (1951); Chetry et al. (2001); Chivers (2001); Geissmann et al. (2008); Khan and Monirul (2008); Kitchell et al. (1979); Menon (2014); Parker (1982); Prater (1971); Srivastava (1999); Srivastava (2006)).

Fig. 4.6 Some unique representatives of nonhuman primate
(**A**) Gorilla (*Gorilla gorilla*)
(**B**) Baboons (*Papio hamadryas*)
(**C**) Slow loris (*Nycticebus coucang*)

4.14.1.2 Classificatory Scheme for Mammalia Tracing Its Origin

At the point of time of classifying mammals into several orders, evolutionary specializations coupled with structural excellences for adaptation are given much priority. It is difficult to be certain about the ancestry of the mammals because the

Fig. 4.7 Charismatic large carnivores (tigers and lions)
(**A**–**C**) Tigers (*Panthera tigris tigris*) in different habitats
(**D**–**F**) Asiatic lion (*Panthera leo persica*) in different postures

only evidence of the early reptiles is in fossils. The living mammals can be divided into three subclasses. The subclass Prototheria, which is now largely extinct, and has three surviving species mainly confined to Australia under the genus *Platypus*, popularly known as "**duck-billed**," and these egg-laying mammals are characterized

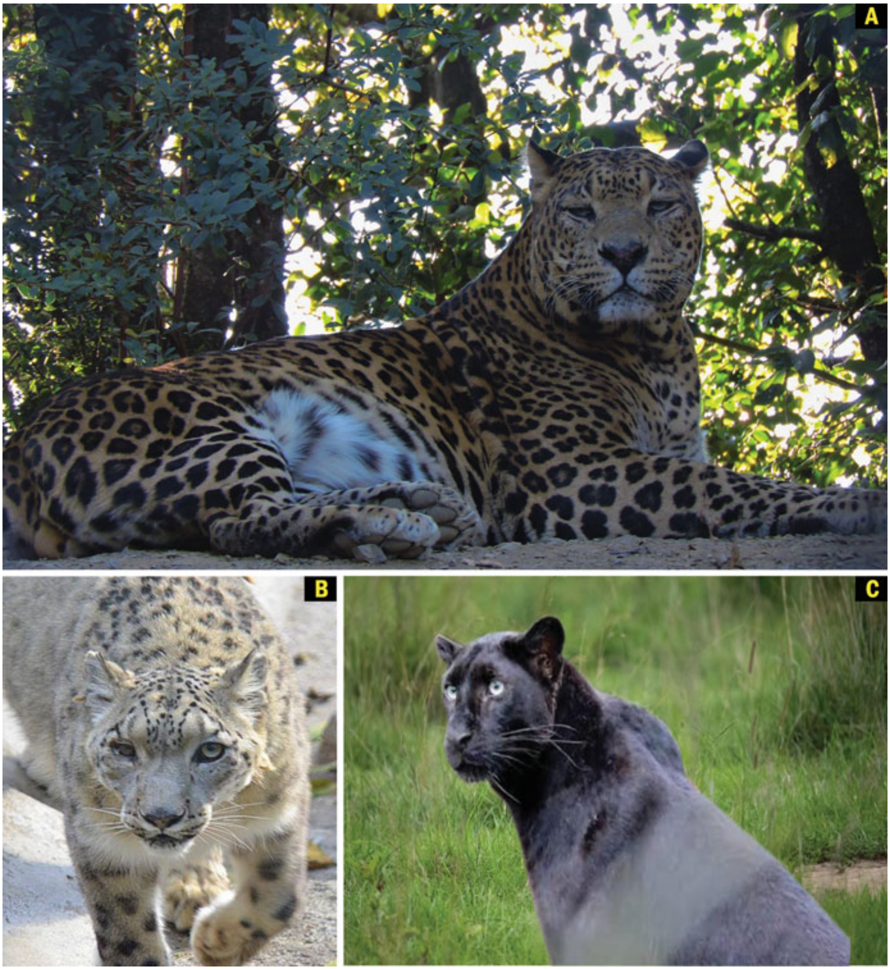

Fig. 4.8 Medium-sized some unique representatives of carnivores
(**A**) Common leopard (*Panthera pardus*)
(**B**) Snow leopard (*Panthera uncia*)
(**C**) Black leopard or melanistic panther (*Panthera pardus*)

by possessing large brains, milk glands, and hair like that of true mammals but without the ability to control body temperature. The subclass Theria contains three groups, one of which is totally extinct.

The other two groups are the marsupials and the placental mammals, confined largely to Australia and South America. They are similar to that of placental mammals in which growing up fetus complete their development inside the mother' s pouch and directly give birth their offsprings/young/juveniles. This group of animals is named as "**placental**" because their youngs are carried in mother's womb and born alive. The blood circulation of the unborn young is linked with

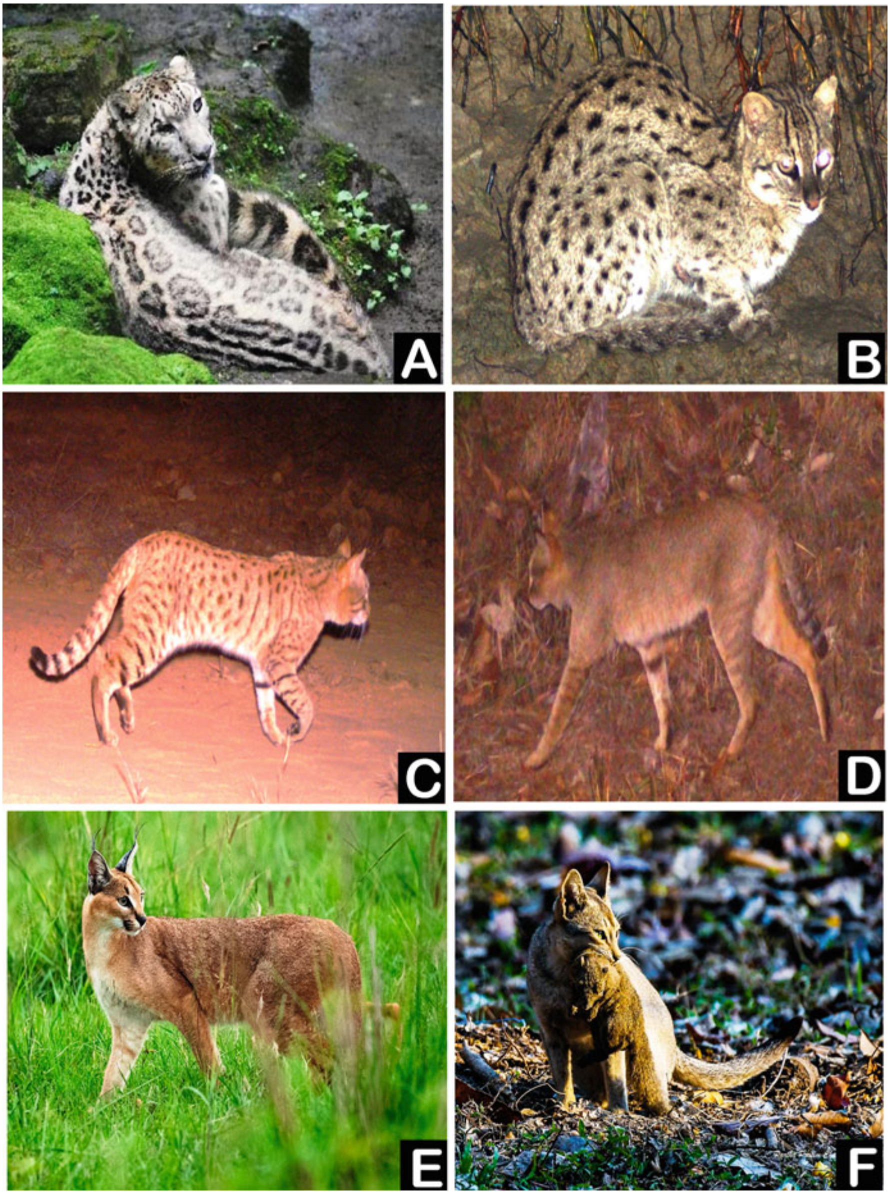

Fig. 4.9 Diversity of cats, representatives of smaller carnivores in Asian subcontinent
(**A**) Clouded leopard (*Neofelis nebulosa*)
(**B**) Fishing cat (*Prionailurus viverrinus*)
(**C**) Asiatic wild cat (Indian desert cat) (*Felis silvestris ornata*)
(**D**) Rusty-spotted cat (*Prionailurus rubiginosus*)
(**E**) Golden or Temminck's cat (*Catopuma temminckii*)
(**F**) Jungle cat (*Felis chaus*) *predating a prey*

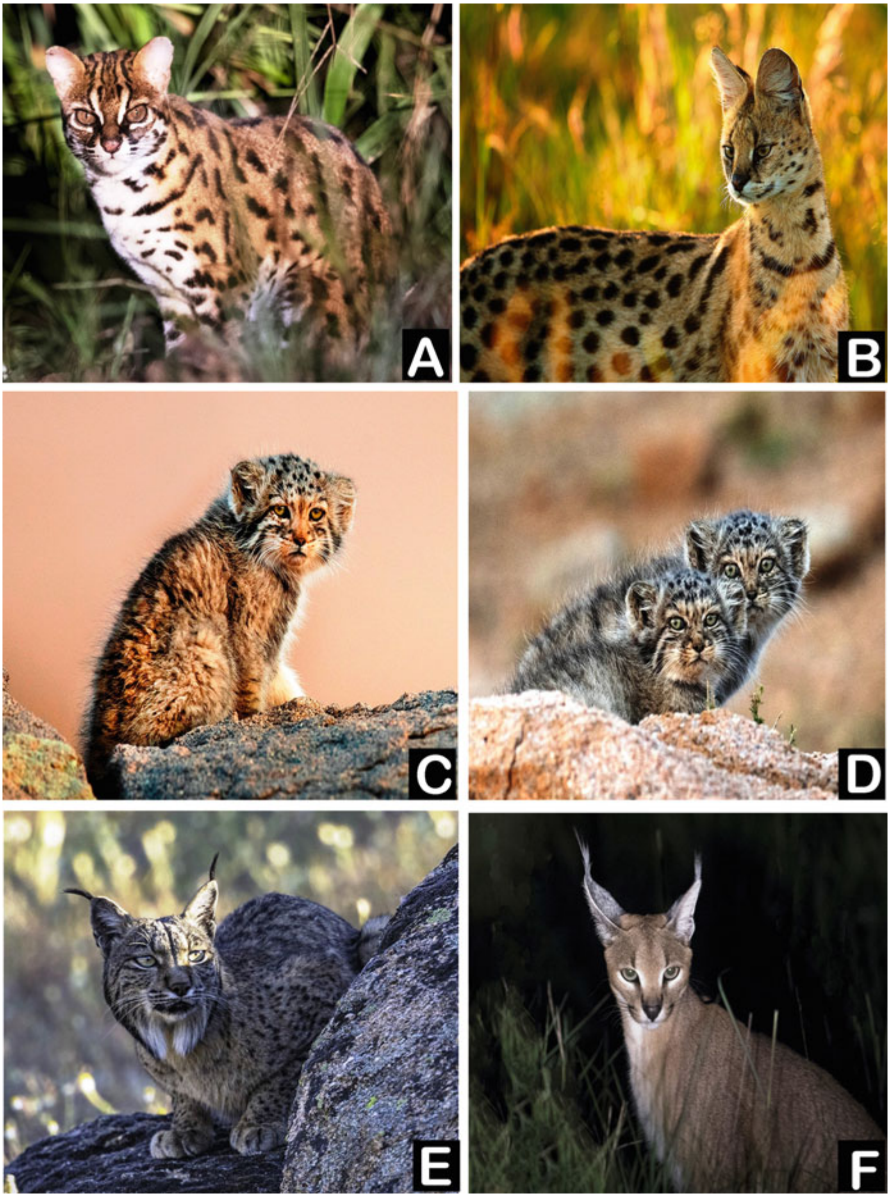

Fig. 4.10 Some very rare and unique representatives of smaller cats of Asian subcontinent
(**A**) Leopard cat (*Prionailurus bengalensis*)
(**B**) Asiatic wildcat (*Felis silvestris*)
(**C**) Pallas' cat (*Otocolobus manul*) – single
(**D**) Pallas' cat (*Otocolobus manul*) – paired
(**E**) Eurasian lynx (*Lynx lynx*)
(**F**) Caracal (*Caracal caracal*)

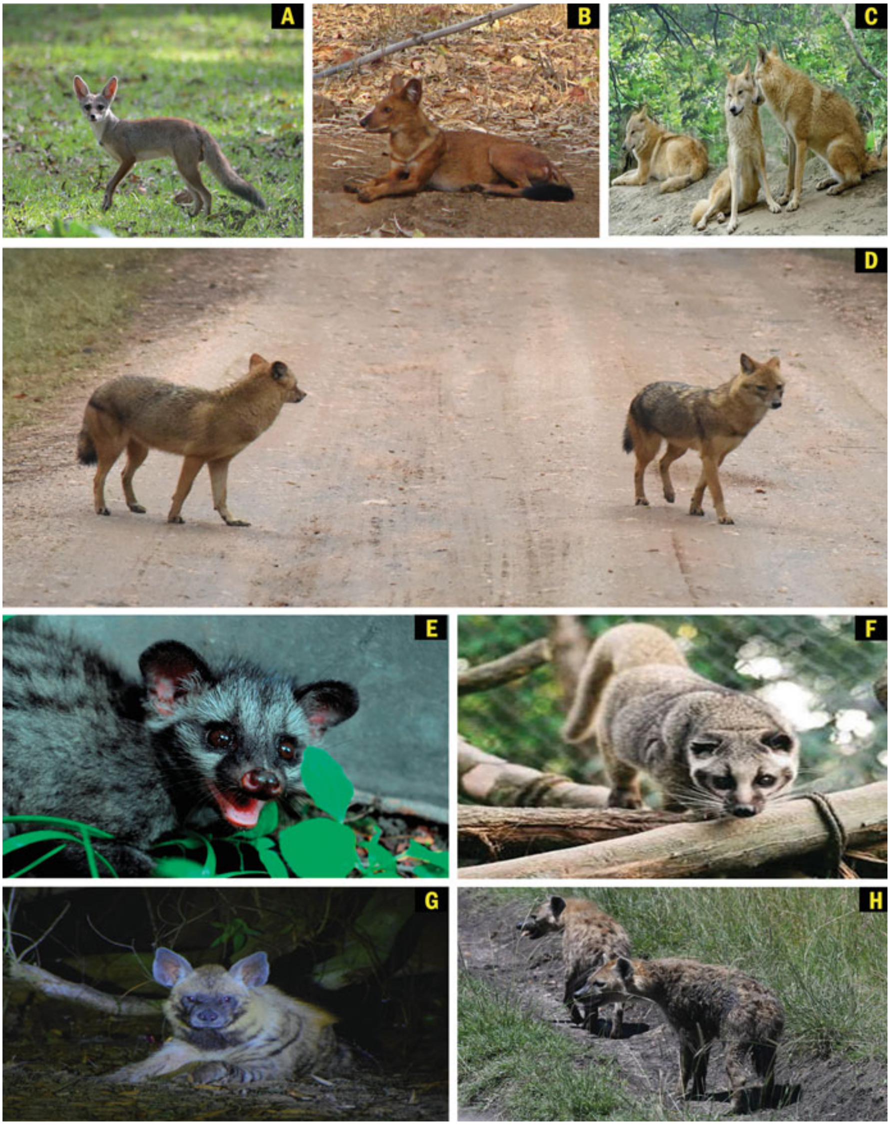

Fig. 4.11 Some representative species of dogs and civets of Asian continent excepting spotted hyena of African continent
(**A**) Fox (*Vulpes bengalensis*),
(**B**) Wild dog (*Cuon alpinus*)
(**C**) Tibetan wolf (*Canis lupus chanco*)
(**D**) Golden jackal (*Canis aureus*)
(**E**) Common palm civet (*Paradoxurus hermaphroditus*)
(**F**) Civet (*Viverricula indica*)
(**G**) Striped hyena (*Hyaena hyaena*)
(**H**) Spotted hyena (*Crocuta crocuta*)

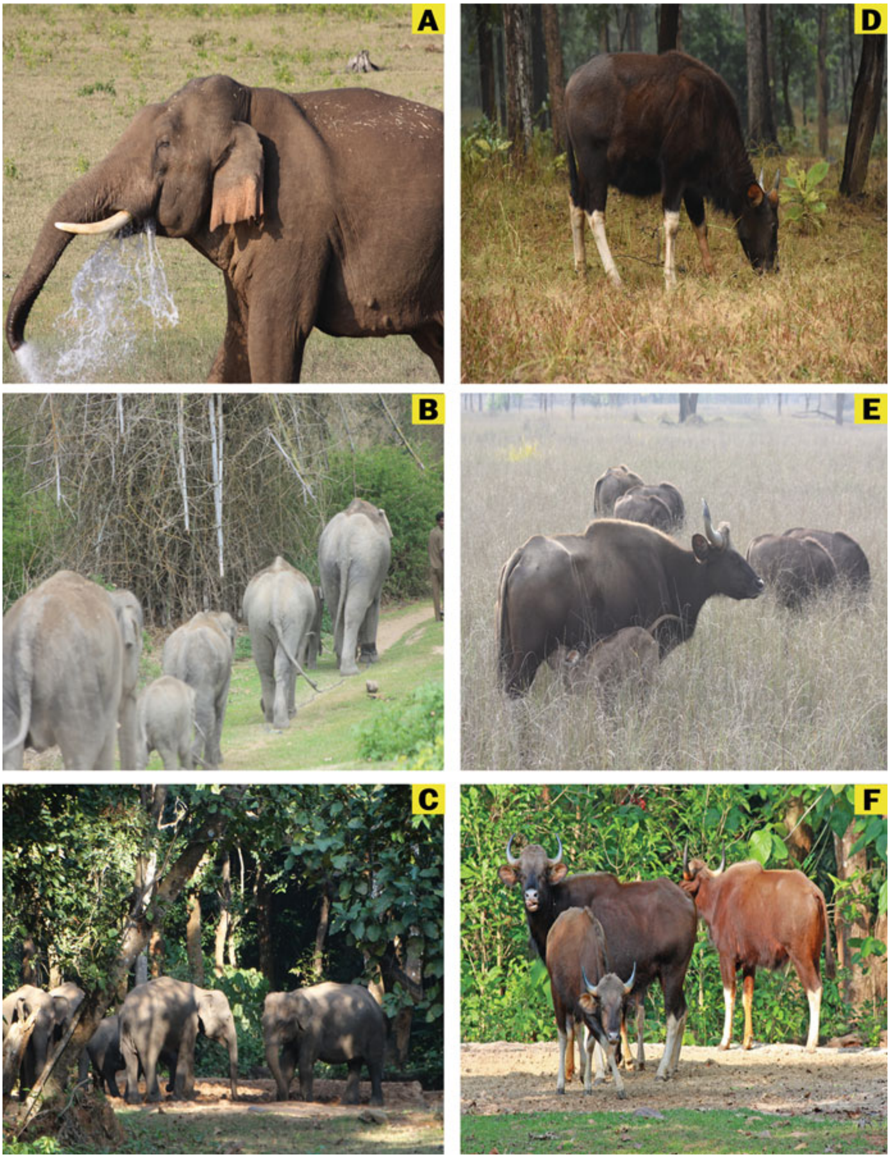

Fig. 4.12 Largest representative of herbivores
(**A**–**C**) Elephants (*Elephas maximus*) in different forms , posture and habitats
(**D**–**F**) Gaur (*Bos gaurus*) in different forms , posture and habitats

the blood stream of the mother by a complex of membranes. These membranes, are bathed on one side by the mother's blood and on the other side by the blood of the offspring, transmit substances required for the growth of the offsprings and carry away its waste products. This system of membranes is called a placenta. The early

Fig. 4.13 Some abundant faunal representatives of deer family of Indian subcontinent
(**A**–**C**) Barasingha or swamp deer (*Rucervus duvaucelii*)
(**D**) Nilgai (*Boselaphus tragocamelus*)
(**E**) Sambar (*Rusa unicolor*)
(**F**) Spotted deer or chital (*Axis axis*)

mammals probably lived largely on insects, as moles and as ant-eaters do today. The true or placental mammals are generally regarded as the highest point of the evolutionary tree. Man is a placental mammal, as are the great apes, the whales, all

Fig. 4.14 Some rare and threatened faunal representatives of deer family of Indian subcontinent
(**A**) Hog deer (*Axis porcinus*)
(**B**) Hangul (*Cervus elaphus*)
(**C**) Blackbuck (*Antelope cervicapra*) – male
(**D**) Blackbuck (*Antelope cervicapra*) – female
(**E**) Barking deer (*Cervulus muntjac*)
(**F**) Chinkara or Indian gazelle (*Gazella bennettii*)

Fig. 4.15 Large ruminants (bovid) and herbivores of Indian subcontinent
(**A**) Takin (*Budorcas taxicolor*)
(**B**) Wild buffalo (*Bubalus bubalis*)
(**C**) Wild goat (*Capra hircus*)
(**D**) Wild yak (*Bos grunniens*)
(**E**) Himalayan brown goral (*Nemorhaedus goral*)
(**F**) Wild ass (*Asinus hemionus*)
(**G**) Himalayan tahr (*Hemitragus jemlahicus*) – female
(**H**) Himalayan tahr (*Hemitragus jemlahicus*) – male

Fig. 4.16 Some representatives of largest group of mammals
(**A**) Rhinoceros (*Rhinoceros unicornis*)
(**B**) Tapir (*Tapirus indicus*)
(**C**) Hippopotamus (*Hippopotamus amphibius*)

the mammals of the Old World, and most of the mammals of the tropics and temperate regions. Modern mammals feed on an astonishing variety of foods: carnivores like dogs and cats eat the flesh of other animals; herbivores like cows and elephants eat grass, tree leaves, and other vegetable matters; rodents, rats, mice, and squirrels, also live mainly on vegetable matters but obtain their food by gnawing rather than by chewing; omnivores such as man will almost eat any food available. Of the aquatic mammals, seals eat fish, sea cows eat only sea plants, and others, like the whalebone whales, live on plankton. The artiodactyls (sheep, goats, cattle, and deers) must have cloven (split) hooves as the salient features.

Fig. 4.17 Some representatives of small mammalian wildlife
(**A**) Flying fox (*Pteropus* sp.)
(**B**) Indian giant squirrel (*Ratufa indica*)
(**C**) Gangetic dolphin (*Platanista gangetica*)

4.14.2 Wildlife Belonging to the Order Primates

4.14.2.1 Morpho-Anatomical Excellence and Classificatory Challenges in the Order Primates

4.14.2.1.1 Uniqueness in Body Architectural Plans of Primates

The most intelligent of the land mammals are the primates, the group to which man himself belongs. The lemurs, monkeys, and apes are derived from tropical tree-living forms, and indeed most of the present-day primates still live in trees. They are omnivorous, eating both flesh and vegetation, although many species rely more or less exclusively on vegetable food. Going against the conventional beliefs, the order Primates under the class Mammalia includes not only groups having monkey or ape but also a number of other groups (a total of six) of animals such as the lemurs, the lorises and galagos, the tarsiers, the New World monkeys, and the Old World monkeys and finally apes and humans. The first three of these groups are referred to as the prosimians while the remainder the simians (Tables 4.4 and 4.5).

Although primate follows the basic mammalian characteristics with some deviation by possessing collar bone or clavicle, five digital limbs bit with the reduction of length of the constituent bones of the digits, development of forward-facing eyes due to the striking reduction of muzzle, diminishing of the power of smell, and enlargement of the brain which remains enclosed within the hard braincase. All these structural developments mostly because of the combination of highly mobile skeleton of primitive design with the pronounced development of brains and associated sensory structures have enabled the primates as to be the most successful groups in the animal kingdom (Rod and Preston-Mafham 1999).

With the exception of man, primates are quadrupedal displaying a considerable degree of variations in limb length, and also in most of the primates, except man, great apes and some monkeys possess long tails which become prehensile in just two subfamilies of New World monkeys, the Atelinae and the Alouattinae. In the prehensile tail, up to one-third of the lower surface at the tip of the tail consists of bare skin, and this gives the monkey a strong grip when the tail is curled around a branch, and in other cases, tails are used mostly to maintain the balance.

Fig. 4.17 (continued) (**D**) Irrawaddy dolphin (*Orcaella brevirostris*)
(**E**) Porcupine: (*Hystrix indica*)
(**F**) Indian pangolins (*Manis crassicaudata*)
(**G**) Hispid hare (*Caprolagus hispidus*)
(**H**) The rufous-tailed hare (*Lepus nigricollis ruficaudatus*)
(**I**) Mongoose (*Herpestes edwardsii)*
(**J**) Smooth-coated otter (*Lutra perspicillata*)
(**K**) Northern palm squirrel (*Funambulus pennantii*)
(**L**) Hoary-bellied squirrel (*Callosciurus pygerythrus*)

Fig. 4.18 Wild boars, panda and pigs of of Indian subcontinent
(**A**) Sloth bear (*Melursus ursinus*)
(**B**) Black Himalayan bear (*Selenarctos tibetanus*)
(**C**) Indian wild boar (*Sus scrofa affinis*)
(**D**) Red panda (*Ailurus fulgens*)
(**E**) Indian wild boar (*Sus scrofa affinis*)
(**F**) Pigmy hog (*Sus salvanius*)
(**G**) Red panda (*Ailurus fulgens*)
(**h**) Piglets of wild boar (*Sus scrofa affinis)*

Table 4.1 Nonhuman primates in India

Species	Common name	General status	**IUCN** status[a]	**CITES** status[b]
Semnopithecus entellus	Hanuman langur or common langur	Common throughout India, but declining	– / Least concern	I
Semnopithecus johnii	Nilgiri langur	Common, but limited to small areas in the south	V	II
Semnopithecus geei	Golden langur	Rare, endangered	R	I
Semnopithecus hypoleucos	Southwestern langur	Common, but limited to small areas in the south	V	II
Semnopithecus priam	Southeastern langur	Common, but limited to small areas in the south	V	II
Semnopithecus hector	Terai langur	Common, but limited to the deciduous forests of eastern and northeastern states	V	II
Trachypithecus phayrei	Phayre's leaf monkey	Generally rare, but common in limited area	R, endangered	I
Trachypithecus phayrei pileata	Capped langur	Generally rare, but common in limited area	R, endangered	I
Macaca mulatta	Rhesus macaque	Reduced, but still common in north	– / Least concern	II
M. radiata	Bonnet macaque	Common in South India	Least concern	II
M. assamensis	Assamese macaque	Forests of Assam	V	II
M. arctoides	Stump-tailed macaque	Brahmaputra River Basin, Assam	R, endangered	II
Macaca nemestrina leonina	Pigtailed macaque	High-altitude forest of northeastern states	Rare, endangered	II
M. silenus	Lion-tailed macaque	Forest tracts of Western Ghats, India	– Rare, endangered	I
Macaca fascicularis	Crab-eating macaque	Andaman-Nicobar Islands, India	Rare, endangered	I
Macaca radiata	Bonnet macaque	Forests and human settlements of Karnataka, in South India	Least concern	II
Macaca leucogenys	White-cheeked macaque	Forests of Arunachal Pradesh in the northeastern India	– Rare, endangered	I
Hylobates hoolock	Western hoolock gibbon	Forest tracts of all northeastern states, India	– Rare, endangered	I
Hylobates leuconedys	Eastern hoolock gibbon	Only in forests of Arunachal Pradesh, India	Rare, endangered	I

(continued)

Table 4.1 (continued)

Species	Common name	General status	**IUCN** status[a]	**CITES** status[b]
Loris tardigradus	Slender loris	Forests in the northeastern India in Brahmaputra River Basin	Rare, endangered	I
Nycticebus coucang	Slow loris	Forests of northeastern India	Rare and endangered	I

[a]IUCN ratings: R, rare; V, vulnerable; In, interderminate; –, not rated; E, endangered
[b]CITES ratings: I, Appendix I, rare and endangered; II, Appendix II, threatened and vulnerable

Despite the absence of strong power smell, scent signals are found to play important roles for communication in some prosimians, especially in the small nocturnal Coquerel's mouse lemur (*Mirza coquereli*), endemic to Madagascar. Sexual pheromones produced by the female primates inform their male counterparts regarding the state of their reproductive cycle. Scent glands occurring in different parts of the body of New World monkeys enable for a steady communication with other members of the same group about the sex, age, and social status and also to delineate territorial boundaries, in between two adjacent social groups. The colors and patterns as found on the face, body, and tails of many primates play important roles in ensuring visual communication.

Besides, flipping up of fur, movement of tails, and facial expressions are also used in visual communication which play important roles in maintaining the social relationships when the individuals remain in close proximity to one another, but for the nocturnal species, different social groups maintain their connections with each other. The individuals of the social groups at the time of foraging in the dense forest canopy keep contacts with others by auditory means emitting sounds depending on the prevailing situations or circumstances. The calls of primates are often associated with the demarcation of territories or as a warning signals to the enemies or as alarm calls to alert not only the members of the social groups but also other wild herbivores such as deers displaying a mutual relationship.

Their mode of life in the trees has given rise to a well-developed sense of sight, and the necessity for quick reactions and muscular coordination in order to swing around the forest has given rise to a highly developed brain. The lemurs are generally considered to be the most primitive of the primates. The monkeys are divided into Old and New World types. The New World monkeys are less advanced from an evolutionary point of view than the Old World monkeys and are chiefly distinguished from them by their flattened snouts. The Old World monkeys include the great apes and man. The most developed of these are the gibbon, orangutans, chimpanzees, and gorillas. Of these, the last two have relatively large brains and a fair degree of intelligence. Although both of them, being the largest among ape animals, started to come down from the trees to live life on the ground, the highest form of bipedality coupled with the acquisition of finer of intelligence has been achieved by most modern primate, the *Homo sapiens*.

4.14.2.2 Classification and Diversity of Species of Primates

The order Primates under the class Mammalia is divided into two suborders – Prosimii and Anthropoidea. The suborder Prosimii includes comparative early evolved primates such as the lorises, lemurs, pottos, and bush babies. All these groups are characterized of having external ears, proportionately larger eyes on faces, and long muzzles terminating in a naked, moist snout and the rhinarium. The suborder Anthropoidea includes more recently evolved primates such as the monkeys, gibbons, apes, and man. This group is having small external ear, reduced muzzles, dry nose, poorly developed whiskers, and mandible.

The suborder Prosimii is subdivided into two infraorders, the Lorisiformes (only a single family, the Lorisidae, which includes lorises from Asia and potto, angwantibo, bush babies, and galagos from the Africa) and the Lemuriformes (two super families – the Lemuroidea (true lemurs and dwarf lemurs with a total of **36** teeth and the indri and the sifakas with only **30** teeth) and the Daubentoniidae (only one species, the weird aye-aye, *Daubentonia madagascariensis*) which inhabit in Madagascar).

The suborder Anthropoidea includes more recently evolved primates such as the monkeys, gibbons, apes, and man. This group is having small external ear, reduced muzzles, dry nose, poorly developed whiskers, and mandible. This suborder is subdivided into two infraorders, the Platyrrhini (New World monkeys characterized by broad noses with lateral nostrils) and the Catarrhini (Old World monkeys, apes, and humans, with narrow noses having downward-facing nostrils). The Catarrhini includes two other families, **viz**., Callitrichidae (marmosets with **32** teeth) and Cebidae (all other monkeys except marmosets, characterized by **36** teeth). The Catarrhini also include four other families such as (**1**) the Cercopithecidae, Old World monkeys from Asia and Africa; (**2**) the Hylobatidae, the gibbons and siamangs from Asia; (3) the Pongidae, the gorilla and chimpanzees from Africa and the orangutan from Asia; and (4) the Hominidae, the man (Rod and Preston-Mafham 1999). The family Lemuridae includes lemurs which are restricted to the large island of Madagascar and to the Comoro Islands in the Indian Ocean.

Order Primates includes **16** families, **69** genera, and **365** species.

Suborder: Strepsirrhini is with the several families, such as (1) Lemuridae (**19** species in **5** genera) that embraces lemur (*Lemur catta*); (2) Lepilemuridae (**8** species under **1** genus) that includes northern sportive lemur (*L. septentrionalis*); (3) Cheirogaleidae (**23** species in **5** genera); (4) Indridae (**11** species in **3** genera) that contains Indri (*Indri indri*); (5) Daubentoniidae (only with **1** species) that is locally named as aye-aye (*Daubentonia madagascariensis*); (6) Lorisidae (**9** species in **5** genera) that embodies Sunda slow loris (*Nycticebus coucang*) and potto (*Perodicticus potto*); and (7) Galagidae (**18** species in **3** genera) that holds Garnett's galago (*Otolemur garnettii*).

Suborder Haplorrhini accommodating the apes as tarsiers, monkeys, and apes possess a number of families such as (1) Tarsiidae (**7** species in **1** genus) which includes western tarsier (*Tarsius bancanus*); (2) Callitrichidae (**41** species in

Table 4.2 List of different endemic wild fauna

Taxa	Examples
Mammals	Lion-tailed macaque *Macaca silenus*
	Nilgiri tahr *Hemitragus hylocrius*
	Indian giant squirrel *Ratufa indica*
	Namdapha flying squirrel *Biswamoyopterus biswasi*
Birds	Narcondam hornbill *Rhyticeros narcondami*
	Nicobar megapode *Megapodius nicobariensis*
	Andaman crake *Rallina canningi*
	Andaman serpent eagle
	Forest owlet *Heteroglaux blewitti*
	Great Indian bustard Ardeotis nigriceps
	Nilgiri flycatcher *Eumyiasal bicaudata*
	Gray jungle fowl *Gallus sonneratii*
	Great Indian bustard *Ardeotis nigriceps*
	Forest owlet *Heteroglaux blewitti*
	Jerdon's courser *Rhinoptilus bitorquatus*
Reptiles	Assam keelback *Amphiesma pealii*
	Darjeeling kukri snake *Oligodon juglandifer*
	Andaman cobra *Naja sagittifera*
	Nilgiri forest lizard *Calotes nemoricola*
Amphibia	Malabar toad *Duttaphrynus hololius*
	Nagaland toad *Duttaphrynus nagalandensis*

7 genera) which mostly contains common marmoset (*Callithrix jacchus*) and Emperor tamarin (*Saguinus imperator*); and (3) New World monkeys' families like Cebidae, Aotidae, Pithecidae, and Atelidae harboring **91** species in **12** genera of capuchin monkeys (*Cebus* spp.) which represent one of the interesting members.

Squirrel monkeys under the genus *Saimiri* in the subfamily Saimirinae include titis (*Callicebus* spp.). Old World monkeys include several families, such as Cercopithecidae (**116** species in **18** genera) that embody hamadryas baboon (*Papio hamadryas*), mandrill (*Mandrillus sphinx*), and *Hanuman langur* (*Semnopithecus entellus*); Hylobatidae (**14** species in **4** genera) that comprises lar gibbon (*Hylobates lar*) and hoolock gibbon (*Hoolock hoolock*); and Hominidae (**7** species in **4** genera of great apes) that includes western gorilla (*Gorilla gorilla*), common chimpanzee (*Pan troglodytes*), and Bornean orangutan (*Pongo pygmaeus*).

4.14.2.3 Adaptability and Global Distribution of Primates

Although the primates of both Africa and Asia exhibit close resemblances, only two genera (*Papio* and *Macaca*) are common to them. Out of four species of great apes (orangutan, chimpanzee, pigmy chimpanzee, and gorilla), all except orangutan are found in Africa. Most of them live in forest and savanna, but some species such as

Table 4.3 Some representative forms of reptiles, birds, and mammals of freshwater ecosystem

Taxonomic group	Common name	Habitat	Remarks
Testudines	Turtles	Rivers, wetlands, ponds, lakes/predators, and herbivores	About 260 species worldwide
Eunectes	Anaconda	Rivers, wetlands, ponds/ predators	Largest snake in the world, up to 10 m long
Nerodia and *Natrix*	Water snakes	Rivers, wetlands, ponds estuaries/predators	All 21 species endangered or threatened
Podicipediformes	Grebes	Lakes, estuaries/predators	21 species
Pelecaniformes	Pelicans, cormorants, anhingas	Lakes, estuaries marine/ predators	
Anseriformes	Swans, geese, ducks, screamers	Lentic and lotic waters/ predators and herbivores	Temporary ponds and wetlands important to many species
Phoenicopteriformes	Flamingos	Shallow lagoons and lakes/filter feeders	Five species, all tropical
Ciconiiformes	Herons and storks	Shallow water/predators	
Falconiformes	Osprey, hawks, eagles	Surface waters/predators	Mainly take fish from surface
Gruiformes	Cranes and rails	Shallow waters/predators	
Cinclus	Dipper	Mountain stream/ insectivore	Dive into clear, running mountain streams to forage
Charadriiformes	Shorebirds and gulls	Shallow waters/predators	
Gaviiformes	Loons	Lakes/predators	
Ornithorhynchus anatinus	Duck-billed platypus	Lakes, rivers/predators	An Australian monotreme
Noctilio	Fishing bat	Lakes, rivers, wetlands/ predators	
Phoca sibirica	Baikal seal	Lake Baikal/predators	Only freshwater seal
Lontra	River otter	Streams, lakes/predators	
Delphinidae	Dolphins	Coastal rivers/predators	Asia and South America
Platanistidae	River dolphins	Large rivers in Asia and Indo-Pacific/predators	Generally blind, locate prey by ecolocation
Sirenia	Dugong, manatee	Tropical, estuarine, coastal rivers/herbivores	
Hippopotamus amphibius	Hippopotamus	Lakes, rivers/herbivores	
Castor	Beaver	Lakes, rivers, wetlands/ herbivores	Northern Hemisphere
Myocastor coypus	Nutria	Rivers, wetlands/ herbivores	South American native introduced in Europe

Table 4.4 Protected forests in India from 2000 to 2019

Year	No. of national parks	Area under national parks (km^2)	No. of wildlife sanctuaries	Area under wildlife sanctuaries (km^2)	No. of community reserves	Area under community reserves (km^2)	No. of conservation reserves	Area under conservation reserves(km^2)	No. of protected areas	Total area under protected areas (km^2)
2000	89	37803.10	485	108862.50	–	–	–	–	574	146665.60
2006	96	38392.12	503	111229.48	1	0.31	4	42.87	604	149664.78
2007	98	38428.88	507	111529.04	5	21	7	94.82	617	150073.74
2008	99	39441.74	510	113123.35	5	21	45	1259.84	659	153845.93
2009	99	39441.74	512	113395.36	5	21	45	1259.84	661	154117.94
2010	102	40283.62	516	113842.87	5	21	47	1382.28	670	155529.77
2011	102	40283.62	518	113998.75	5	21	52	1801.29	677	156104.66
2012	103	405000.13	526	114933.44	5	21	59	2012.93	693	157467.50
2013	102	40500.13	532	117123.63	19	30.94	64	2232.61	717	159887.31
2014	103	40500.13	535	118290.66	43	58.22	64	2232.61	745	161081.62
2015	103	40500.13	541	118866.44	44	59.51	71	2548.82	759	161974.90
2016	103	40500.13	543	118917.71	45	59.66	72	2566.20	763	162043.70
2017	103	40500.13	544	118931.80	46	72.61	76	2587.95	769	162092.49
2018	104	40501.13	544	118931.80	46	72.61	77	2594.03	771	162099.47
2019	104	40501.13	551	119775.80	127	525.22	88	4356.49	870	165088.36

Source: National Wildlife Database, Wildlife Institute of India

Table 4.5 Protected areas of India (July, 2019)

	No.	Total area (km^2)	Coverage % of country
National parks (NPs)	104	40501.13	1.23
Wildlife sanctuaries (WLSs)	551	119775.80	3.64
Conservation reserves (CRs)	88	4356.49	0.13
Community reserves	127	525.22	0.02
Protected areas (Pas)	870	165158.54	5.02

Geographical area of India = **32, 87,263** (km^2)
Forest cover of India (FSI, 2017) = **7, 08,273** (km$^{2)}$
Percentage area under forest cover =**21.54**%

the baboons and patas monkey, *Erythrocebus patas*, instead of arboreal life prefer to adapt themselves to a life on ground.

Within the rain forest, different primates have adapted themselves to widely differing ecological niches which broadly speaking are based on the system of vertical stratification; the larger species tend to be terrestrial or live close to the ground, while the smaller species are more arboreal. The topmost stratum of forest canopy, especially in the periphery, is warmer because of receiving solar rays than the lower stratum and inner part of the forest. Availability of sunlight is directly proportional with the primary productivity as revealed by the production of plenty of edible fruits, flowers, leaves, and insect fauna alongside providing a shelter away from the reach of predators. However, most fruits are grown on the extreme terminal and peripheral parts of the wide-spreading branches which cannot support the weight of the large animals and thus necessitated to adopt required behavioral patterns for food collecting, locomotion, etc. differing from those which select lower levels as their habitats.

These complex ecological interrelationships have prompted to study the adaptability of such shy but highly movable animals living in the upper strata of the dense forests.

4.14.2.4 Bioecological Uniqueness of Primates

Primates being the most charismatic group with their forward-facing eyes and human-like faces remind us of our own origins and are represented by 19 species, of which small and slender loris is restricted to the tropical rain forests of South India, while the comparatively bigger slow loris (*Nycticebus coucang*) inhabits the denser forests of Northeast India, especially along the river ecosystems. They are strictly nocturnal and very secretive and therefore unlikely to be seen. Their main features include owl-like eyes and very round, pale, furry bodies. The hoolock or white-browed gibbon, *Hylobates hoolock*, of the family Hylobatidae is the only ape found in the region. Monkeys, being a part of every Indian landscape, are the most common member of the order Primates which include those animals considered immediate predecessors of human being. The members belonging to the order

Primates represent the most evolved of the mammalian fauna and are identified by a combination of characteristics rather by one or more exclusive ones. Since all primates have evolved from arboreal ancestors, traits associated with arboreality are a common link. An adaptive development of arboreality is prehensile hands and feet, with thumb and big toe opposable to the other digits. Arboreality also has led to the reduction of olfactory abilities; the snout is reduced and the face relatively flattened.

All other species belong to the family Cercopithecidae, which is subdivided into seven species of macaques (Cercopithecinae) and five species of langurs (Colobinae). The tail of these species may be as long or longer than the head and body combined, as in some macaques, such as *Macaca sinica* and all of the langurs (*Semnopithecus entellus*) small and stunted as in *M. arctoides* and *M. nemestrina* or all together lacking as in *Hoolock hoolock.*

4.14.2.5 The Primates of India: Status, Trends, and Conservation

The primates by virtue of their abilities to exert very important feedback control at the ecosystem level by profusely help controlling the green biomass alongside ensuring pollination and seed dispersal, reducing pest attacks, and recharging soil organic fertilizers have become the parts and parcels for the maintenance of homeostasis of the forest ecosystem, especially playing critical roles for the forest regeneration and survival. Besides, the diversity of Primates can be considered as to be very good predictor of the richness of other mammalian fauna and ecological health of the entire ecosystem. India has long been known as one of the rich primate areas of the world, both in species diversity and population abundance. Twenty-two **(22)** species of nonhuman primates occur in India, of which six species of macaques, five of langurs, two of lorises, and species of gibbon have become happy residents at varied forms of forest habitats. (Table 4.1, **Figs. 4.1, 4.2, 4.3, 4.4, 4.5, and 4.6**).

In India, the rhesus macaque and the *hanuman langur* are considered among the largest populations of any nonhuman primate in terms of population abundance, just like the similar distinction of the baboons of Africa. In the **1950s**, monkey populations in northern India were variously estimated from **10** to **20** million (Corbet, 1990; Pandit, 1991), although these estimates were based on the judgments of natural historians and not on scientific surveys. After completing first field survey in the year in **1960**, rhesus population of India was estimated to be less than **2** million (Southwick et al., 1965). These rhesus populations as per their potential for the cause of human beings are concerned rank first among other species of primate species in the world for different biomedical and eco-toxicological research.

4.14.2.5.1 Monkeys: The Most Common Wildlife in India

The commonest monkey is rhesus macaque which is distinguished from all other species by its red button. The second most common monkey is the common langur which is characterized by long limbs and tails, agile behavior, and black face. Monkeys are part of almost every Indian scene, crowding around villages and aggressively roaming in the cities. The commonest monkey in India is the rhesus macaque which is distinguished from all other species by its red bottom. The second most plentiful monkey is the common langur, also known as Hanuman monkey which inhabit in most of the Indian forests. The Phayre's leaf monkey occurs in the state of Tripura in India and Bangladesh. The hoolock gibbon is the only true ape in the subcontinent where its range extends from the country of Burma into the forests of the State of Assam in India and Bangladesh Hill tracts.

4.14.2.5.2 Langurs: The Diversified and Abundant Primates in Indian Subcontinent (Fig. 4.2)

Langurs, the long-tailed belonging to the family Cercopithecidae and subfamily Colobinae, are distributed throughout the length and breadth of India enjoying the habitats ranging from the high-altitude mountains to the coastal belts. They differ from other Old World monkeys such as baboons, guenons, and macaques by possessing three different characteristics: (**1**) devoid of cheek pouches for the storage of food for a period of time; (**2**) females who do not exhibit swelling from the perineal part of the body as a mark of reproductive cycle; and (**3**) presence of large and complex stomachs as the sites in the gastrointestinal tracts to facilitate bacterial fermentation of freshly harvested green and mature leaves (**Fig. 4.2**). Eight different species of langur as encountered from different corners of India are as follows.

*4.14.2.5.2.1 Hanuman Langur (**Semnopithecus entellus**)*

The most widely distributed species of nonhuman primate in India is the ***Hanuman langur*** or common langur (*Semnopithecus entellus*). It occurs throughout the country except in the westernmost sections of the Rajasthan desert and the easternmost areas of India bordering Burma (Wolfheim, 1983). The *Hanuman langur* is the truly sacred monkey of India, though all primates share this distinction to some extent. Despite its widespread distribution and sacred status, there are two points of concern. The different nationwide primate surveys have confirmed it as the most abundant monkey species in India, and several studies indicate that its populations are declining. The *Hanuman langur* (*Semnopithecus entellus*), being the most abundant and widely spread species in India, lives in a variety of habitats from plains to few thousand meters altitude (**4000** meters) in the Himalayas and from dry tropical forests to open forests, scrub jungles, and arid rocky areas with xerophytic vegetation. This species is distinguished by its silver-haired body with black-colored face, ears, forehands, and soles of the feet. Besides, gray–white whiskers are present over the face. The young also has to adjust its behavior towards other adults in the group. The youngs of this primate have to learn to adjust to their own siblings and other young of the same age. They practice this during social play which often involves testing each other's strength and trying to suppress the other young to a lower social position. The mothers may vigorously intervene in such a process and try to protect the interests of their own young. In this complex social environment, the youngs grow and adjust themselves to take up their responsibility as the social members of their groups (**Fig. 4.2**).

*4.14.2.5.2.2 Golden Langur **(Semnopithecus geei)***

The name of this medium-sized (just less than **3** feet in length) langur monkey is derived from the silky golden-colored body with entirely black face surrounded by long and reddish hairs. A long tessellated tail aids in the climbing and movement of this animal. This nonaggressive docile member of the primates lives in the mixed deciduous forests in between Sankosh and Manas rivers in the northeastern part of India (**Fig. 4.2**).

*4.14.2.5.2.3 Nilgiri Langur **(Semnopithecus johnii)***

Although the body color of this medium-sized langur (length around **3** feet) is glossy black throughout the body, the head is covered by non-radiating long yellowish brown hairs. It possesses a long tail, the base of which is grizzled. This species being an inhabitant of tropical moist deciduous forest is found in the hilly tracts of several parts of South India, mostly in the forest tracts of Western Ghats.

*4.14.2.5.2.4 Southwestern Langur **(Semnopithecus hypoleucos)***

This medium-sized (length in between **3** and **4** feet) and brownish-colored langur is characterized by having no crest and a backwardly directed looped tail**.** They have restricted distribution from the State of Karnataka to Kerala, India.

*4.14.2.5.2.5 Southeastern Langur **(Semnopithecus priam)***

This crested medium-sized langur (little more than **3** feet) with a backwardly looped tail is devoid any streak between the eyes and ears, and the gray colors of their body coat are comparatively more paler than other langur species. They are distributed in the forest tracts of the states of Andhra Pradesh and Karnataka, mostly in the dry deciduous forests with scrublands.

*4.14.2.5.2.6 Kashmir or Chamba Langur **(Semnopithecus ajax)***

This langur without any crest silvery-brown back colors in the back with pale creamish tinge of color in the ventral side. The colors of the feet and arms are comparatively dark. The head appears to be blunt, flattened, and circular encircled by long creamy furs. They are mostly found in the forest tracts of the states of Himachal Pradesh and Jammu and Kashmir, India (Fig. 4.2).

4.14.2.5.2.7 Terai Langur ***(Semnopithecus hector)***

This medium-sized (around **3** feet) creastless langur are bicolored, grayish brown on the dorsal side and pale creamy on the ventral side. The forwardly looped tail is smaller than the body length. They inhabit mostly in tropical moist and dry deciduous forests of the states of eastern and northeastern India.

4.14.2.5.2.8 Capped Langur or Leaf Monkey ***(Trachypithecus phayrei pileatus)***

This langur is medium-sized (**around 3 feet**) but robust in build possessing proportionately long tail (**around 4 feet**). The color of the face (orange to golden red) contrasts with the dark gray color of the main body of this species. The long hairs in the head are non-radiating. They are found to occur in northeastern states of India extending their distribution to Indo-Burma border (**Fig. 4.2**).

4.14.2.5.2.9 Velvet Langur of Old World ***(Chlorocebus pygerythrus)***

This medium-sized (**3** feet) Old World monkey mostly inhabit in the riparian forests and savannas of Africa and characterized by body coats of velvet texture and the gray colors in sharp contrast to black color of facial region. This animal always remains in social group comprising of **10–50** individuals. Mostly they are herbivorous but occasionally feeds eggs of birds (Fig. 4.2).

4.14.2.5.3 Phayre's Leaf Monkey (***Trachypithecus phayrei***)

This dark ashy brown langur measuring a little more than **2** feet exhibits double colors – black in the head and tip of the tail and silvery white in the rest part of the body. However, within the black face, the lips and the surrounding areas of the eyes and mouth remain white in color. It is only recorded in the deciduous forest of the State of Tripura, India, and its habit preference is determined by the bamboo and banana plants in the vicinity of rivers and streams (Fig. 4.2).

4.14.2.5.4 Macaque Monkeys (Figs. 4.3, and 4.4)

This group of monkeys under the genus *Macaca*, characterized by the olive-brown colors and comparatively short tails, is inhabited in all the nook and corners of the Indian subcontinents. This wide range of distribution of these monkeys has been possible mainly because of their adaptation to a widely varied diets mostly procured from the floor of the forest and human settlements, religious places, etc., avoiding intercommunity competitions especially with arboreal faunal components such as leaf-eating langurs and frugivorous squirrels. Out of the 23 macaques found all over the globe, **8** different species of macaques occur in different eco-regions of India.

In Indian subcontinent, there are seven species of *Macaca*, ranging from the sea level to altitudes of **3000 m**; the rhesus macaque, *Macaca mulatta*, belonging to the subfamily Cercopithecinae is the most widespread of all Indian primates and becomes very unique by its ability to live in close association with human beings Among the primates, the lion-tailed macaques (*Macaca silenus*) are being considered as one of the world's most threatened animal primates, sustaining against all kind of environmental odds in the evergreen forests of the Western Ghats of South India, with a total population of about **800**. Only the pigtailed macaques (*M. assamensis*) occur in the dense evergreen forests of the northeastern India, while the carb-eating (*M. fascicularis*) is restricted to a few islands in the Nicobar group. In the langur group, the Nilgiri langur (*Trachypithecus johnii*) is a multihabitat species occurring in addition to the sholas, in the evergreen forests with the temperate altitudinal influence in the Western Ghats.

*4.14.2.5.4.1 Rhesus Macaque (**Macaca mulatta**)*

This species represents the most widespread monkeys among all Indian primates, and they are also widespread in Southeast India. Its physical appearance includes gray-colored long hair coatlong, pink-colored naked face, whereas in the posterior end, the colors of the furs change to reddish-orange. The size of the females is smaller than males, and their distinct mammae remain exposed to outside. Red ischial callosities occur in this species. This gregarious and agile species maintain close contact with the human beings while dwelling on the human settlements as well as in religious places. The males often display aggressive behavior (Fig. 4.3).

*4.14.2.5.4.2 Assamese Macaque (**Macaca assamensis**)*

The body of this medium-sized (a little more than **2** feet in length) Old World monkey is covered by yellow-brown hairs on all parts of the body except the face which is purple-pinkish in color. It has a short tail (around **1** foot in length) densely clothed by hairs. This species is now found in the southern sectors of the Brahmaputra River in the tropical deciduous forests in the state of Assam, northeastern India (**Fig. 4.3**).

*4.14.2.5.4.3 Lion-Tailed Macaque (**Macaca silenus**)*

The very intersecting gregarious form of apes (length around **3** feet) with proportionately long face which is surrounded by a deep brownish ruff. A noticeable curved tail with a tuft of hairs at the terminal point adds new dimension in its appearance. It enjoys undisturbed evergreen forest tracts of mountains of Western Ghats, India (**Fig. 4.4**).

*4.14.2.5.4.4 Pigtailed Macaque (**Macaca nemestrina leonina**)*

This stout monkey (length nearing to **3** feet) is provided with strong limbs, a broad flattened head having tuft of hairs at the center, and a striking presence of **V-shaped** stripe over the forehead. It is with small-sized bicolored tail with black-colored fur on the above and yellowish-brown below. It is rarely seen in the northeastern India, residing in the base of the hills having an altitude of less than **1500** meters.

*4.14.2.5.4.5 Stump-Tailed Macaque (**Macaca arctoides**)*

This modest-sized ape having a length of around 3 feet possesses a short tail, shaggy hairs on the head and shoulder with lengths of **4–5** inches, and dark brown color on the dorsal and pale on the ventral side of the body. They inhabit in the hilly forest tracts of Brahmaputra River Basin of northeastern India.

*4.14.2.5.4.6 Crab-Eating Macaque (**Macaca fascicularis**)*

This dusky-colored monkey, measuring about little more than **2** feet, is with hairs on the crown, but hairs are backwardly directed from the brows. Being an inhabitant of the tropical rain forest, this monkey is found to inhabit in the Andaman and Nicobar Islands, India.

*4.14.2.5.4.7 Bonnet Macaque (**Macaca radiata**)*

This medium-sized (around **3** feet) is distinguished by a bonnet-like cap formed by gray hairs and a long tail. The color of the face undergoes seasonal changes from pinkish to pale red in tune with their reproductive activities. They have restricted distribution mainly in the states of Karnataka and Maharashtra, India, inhabiting in the human settlements near dry deciduous and evergreen forests (**Fig. 4.3**).

*4.14.2.5.4.8 White-Cheeked Macaque (**Macaca leucogenys**)*

This species of macaque is mainly found in the broad-leaved evergreen and coniferous forests of Arunachal Pradesh in the northeastern India. This macaque species appears to be very similar to that of Assamese macaque, but the presence of white elongated whiskers on the rounded face has differentiated this species from others.

4.14.2.5.5 *Hoolock Gibbon: Western Gibbon (**Hoolock hoolock**) and Eastern Gibbon (**Hylobates leuconedys**)*

The only ape species [(slender, tail less, medium-sized (length little more than **3** feet)] in India is the hoolock gibbon which also ranks second in respect of its size among other gibbons of the world. This gibbon species is only found to inhabit forest tracts of Northeast India around the south of Brahmaputra and Dibang rivers and even eastern Bangladesh, northern Myanmar (Burma), and a small area of southern China (Chetry and Rekha Chetry 2011). The distinguishing features include small and round head with the presence of white band of furs around the eyebrows. Their facial complex is very unique in having widely spaced nostrils and blunt snout.

Presently, two established species of hoolock gibbons are in existence, viz., the western hoolock (*Hylobates hoolock*) and the eastern hoolock (*H. leuconedys*) in India and adjoining neighboring countries. In India, the western hoolock gibbon (*Hoolock hoolock*) is distributed in forest tracts of all the seven northeastern states, viz., Assam, Arunachal Pradesh, Tripura, Meghalaya, Manipur, Nagaland, and Mizoram, whereas the eastern hoolock gibbon (*H. leuconedys*) has very restricted distribution which is confined only within two states, mainly in the state of Arunachal Pradesh and certain parts of Assam, having similar kind of habitats (Geissmann, 2007; Chetry and Rekha Chetry 2011). Out of these two species, the western hoolock is considered as endangered, whereas the eastern hoolock is vulnerable (IUCN, 2010). The western form is considered less threatened mainly because of the larger habitat areas supported by the assemblages of large broad-leaved plant species provided with contiguous canopy in the wet evergreen and semievergreen forests (Walker et al. 2009). However, the species is threatened throughout its geographic range by population decline primarily due to habitat destruction (Molur et al. 2005). At present, *H. hoolock* is categorized as endangered globally (IUCN 2006). The gibbons display very fascinating eco-ethological attributes such as monogamy, small family groups and brachiatry mode of movement, strictly frugivorous feeding habit, spatial inflexibility, and strict in maintenance of territory. All these characteristics make gibbons highly susceptible to habitat fragmentation and disturbance (Molur et al 2005; Walker et al., 2009).

4.14.2.5.6 Lemurs

Lemurs, like macaque and langurs, take leaves and fruits of plants as their food and lead a complete arboreal life. Development of pointed snout gives the lemur a foxy animal look. Like all other primates, the lemurs are provided with grasping hands and prehensile feet having opposable digits. The Old World apes is having only one family in India, Lorisidae, which includes three major species of loris.

4.14.2.5.6.1 Slow Loris (***Nycticebus coucang)***

The body of this nocturnal and small-sized (around 15 inches) apes (family Lorisidae: subfamily Lorisinae) depicts stout appearance with rounded head and circular eyes surrounded by brown color fur. It has a very short tail and only one (second) clawed toe. The colors of its body fur range from milky gray to pale yellow in different phases of its life cycle. The have developed very unique pattern of adaptability by hanging upside down from the branches despite having no tail (**Fig.**

4.6). In India, it is found in the tropical rain forest in the river basins of Brahmaputra River in the northeastern part of India.

*4.14.2.5.6.2 Slender Loris (**Loris tardigradus**)*

This small-sized (less than **1** foot) species is considered as the southern counterpart of Bengal slow loris having been endowed with an indistinct spinal stripe and circular brown-colored eye patches. It is with a small (length just around 1 foot), slender, and lean body appearance endowed with long limbs and large ears but without tail. It is very scanty in its abundance, restricting to only certain forest tracts of southern part of India. They are mainly found from the riparian forests of the River Godavari in the Eastern Ghats and the River Tapti of the Western Ghats.

4.14.2.5.7 Gorilla ***(Gorilla gorilla)***

This largest species of the order Primates roams the rain forest in family groups of usually **5–10**, comprising of a dominant male, females, and their young without exhibiting that much of seasonal variation in respect of their behavior. Some sleep at night in nests of branches, and others, including older males too heavy to climb, sleep at the foot of the tree. They feed on bamboo, fruit, and succulent plants. They generally live above **10,000 ft (3000 m),** but during the season of heavy rainfall, they descend down to the lower slopes to feed on new bamboo branches/shoots.

They undertake mating once in a year. A female bears one baby weighing about **4 lb (1.8 kg)** after **9** months of pregnancy and suckles the infant for **2.5–3** years. The young stars start to walk at **4–6** months old. Females are sexually mature at **7** years old and can give birth every **3.5–4.5** years but usually raise a baby to maturity only once in **7** years; disease, climbing accidents, and leopard take a heavy toll of the youngsters. Males take longer time to become mature. The males often kill suckling infants so that the females can again be prepared soon to mate again (**Fig.** 4.6).

4.14.2.5.8 Chimpanzees ***(Pan troglodytes)***

Chimpanzees, under the class Mammalia, of the order Primates and family Pongidae are part of the group known as the great apes. Their closest relatives are the gorilla and the orangutan. Their strong similarities to human beings have made this member of apes appealing to young and old. The common chimpanzee, *Pan troglodytes*, is found to inhabit in the forest habitats spreading across Equatorial Africa as far as Tanzania. The pygmy chimpanzee or bonobo, *Pan paniscus*, restricts their distribution in the areas of tropical rain forest in the region bounded by the Zaire and Lualaba rivers in Zaire. The length of males of chimpanzee varies from **30 to 66** inches, and weight reaches to a maximum of **40** kg. The females are bit lesser in length (**28–33** inches) with a maximum weight of **30** kg. The body of chimpanzee remains covered with black coats with some white hairs on the muzzle. Their skin is light and only the face is pigmented. Both sexes tend towards baldness. Their ears are noticeably large and protrude from the head. As with all apes, chimpanzee does not have any tail. Three subspecies of chimpanzees are recognized: the western (*Pan troglodytes*), the central (*Pan troglodytes troglodytes*), and the eastern (*Pan troglodytes schweinfurthii*). All chimpanzee populations are now in jeopardy today, and chimps are no longer found in some countries that were once part of their range.

4.14.2.5.9 Baboons (***Papio hamadryas)***

Baboons being among the largest non-hominoid primates are represented by five species, which are all native to the African subcontinent. Living in large troops, this type of primates unlike the arboreal langurs dwells on the ground with omnivorous food habits. This primate is unique for the striking sexual dimorphism where males are almost double in sizes than females. Besides, the protruded head of adult males is caped with the radiating silver white hairs (**Fig. 4.6**).

4.14.3 Wildlife Belonging to the Order Carnivora and other Mammalian Wild fauna of Ecological Significance

Wildlife Belonging to the Order Carnivores

Many species in other orders, past and present, have been meat-eaters, but only members of the Carnivora stem from ancestors whose fourth upper premolar and first lower molar were adapted to shear through flesh. In species with more vegetarian inclination, such as pandas, they have reverted to grinding surfaces. Carnivores are equipped with four marvelously engineered carnassial (scissor) teeth (**Figs. 4.1, 4.7, 4.8, 4.9, 4.10, 4.11, and 4.12**).

In fact, diet is the root of one major division within the Carnivora: that between large and small species Tactics of hunters. Many living Carnivora are now adapted to either mixed (omnivorous) or even largely vegetarian diets, but meat eating has been their specialty diets in the past. Although easier to digest than the plant materials, the animal prey is harder to catch, and much of the fascination of the carnivores lies in the stealth, efficiency, precision, and almost unfathomable complexity of their predatory behavior.

4.14.3.1 Morpho-Anatomical Uniqueness in the Order Carnivora

The skeletons of all carnivores share evolutionary ancient modifications of the limbs – the fusion of the bones in the foot. The advantages of a long stride when running may explain the relatively undeveloped collar bone (clavicle), which is free at both ends and function of a large clavicle. The retractile claws so typical of cats are not common to all carnivores; they are only found among the Viverridae (some civets and genets). Canids have in contrast digging claws which they use, among other contexts, when catching foods. A few unusual reproductive traits are found in carnivores. The penis of all members of carnivores except hyenas contains an elongate bony structure known as the baculum or as penis, the shape of which is characteristic for each species. The so-called copulatory tie, which "locks" male and female together during copulation, occurs only in canids and may function in sperm competition. The senses of the carnivores are all acute. Perhaps most intriguing is their refined ability to use scent not only to find prey (and to escape predators) but as a method of communication. Apart from the signal value of urine and feces, which are deployed at strategic locations, most carnivores have several odorous skin glands.

4.14.3.2 Classificatory Scheme of Carnivores

The order Carnivora includes **15** families, **123** genera, and **283** species: (**1**) family Mustelidae (marine otters, black footed ferret, etc.) with **59** species and **22** genera (weasels); (**2**) family Mephitidae (skunks, etc.) with **12** species and **4** genera; (**3**) family Procyonidae (raccoons) with **14** species and **6** genera; (**4**) family Ailuridae (red panda) with sole representative of the genus; (**5**) family Otariidae; (**6**) family Phocidae (seals – fur seals, eared seals, monk seals, sea lions, etc.) with **35** species in **20** genera; (**7**) family Odobenidae (walrus) with only member of the genus; (**8**) family Ursidae (polar beer, brown bear, etc.) with **8** species in **5** genera; (**9**) family Canidae (jackal, fox, wolf, wild dog, etc.) with **36** species in **13** genera; (**10**) family Hyaenidae (hyenas) with **4** species in **3** genera; (**11**) family Felidae (cats – tiger, lions, leopard, jaguar, wildcat, etc.) with **36** species in **11** genera; (**12**) family Herpestidae (mongooses) with **35** species in **14** genera; (**13**) family Eupleridae (Malagasy carnivores) with **8** species in **7** genera; (**14**) family Viverridae; and (**15**) family Nandinidae (Asiatic palm civet) with **15** genera and **38** species.

4.14.3.3 Body Architectural Plans of Carnivores: Adaptive Strategies

Adapting to their needs, carnivores have become well-equipped for catching their prey with sharp claws, strong teeth for tearing flesh, and an ability to run faster than their prey. Most have developed good eyesight or sense for tracking down the animals they wish to eat. They are equipped with four marvelously engineered carnassial (scissor) teeth. The cats are extremely pure examples of carnivores because their teeth are adapted solely for tearing flesh, and they have no other organs for the mastication and chewing of their foods. All of these have restricted them entirely to flesh, because flesh can be swallowed whole and digested unlike vegetables. Lions and tigers are the best known big cats. A mammal closely related to cat is the hyena. These animals were once thought to be scavenging species, but they often are capable to catch living prey such as antelopes. Unlike the cats, the dogs, foxes, and wolves have retained some chewing ability and have some molar teeth. They tend to hunt in packs and can run long distances. The bears depicting their similarities with dogs are also capable of eating a mixed diet. The marine carnivores are probably descended from the land carnivores of the dog type. They include the seals, which live almost exclusively on fish, and the walrus, which uses its huge canine teeth or tusks to open the shellfish on which it feeds. In these animals, legs have become modified for swimming. Another successful group of animals with perfection in adaptability is the rodents, the gnawing animals. Best known are the rats and mice, but the family also includes squirrels, porcupines, rabbits, etc.

4.14.3.4 Major Indian Representative of Wild Fauna Belonging to the Order Carnivora (Figs. 4.1, 4.7, 4.8, 4.9, 4.10, 4.11, and 4.12)

4.14.3.4.1 Wildlife Belonging to the Cat Family

4.14.3.4.1.1 Tigers ***(Panthera tigris tigris)***

Tigers, being the top predators of forest ecosystem, determine the functioning of the said ecosystem and the conservation of biodiversity, the synergistic effects of which guarantees the well -being of peoples by way of providing so many ecosystem services such as good quality of anf foods along with ensuring the climate sequirity. In India, natural habitats of tigers ranges from the forest tracts of high mountains to riparian mangrove swamps near coastal area, from the evergreen forests to dry and moist deciduous forests, and from grasslands with tall grasses. Therefore, conservation of tigers based on eco-ethological studies on them serves the purpose of protecting and conserving varied forms of eco-regions along with their biodiversity.

These majestic big cats fascinate the naturalists by their unique behavioral manifestation. The tiger being the largest member of the cat family has a body length of **8–10 ft** and a body weight of about **274 kg.** This wild beast is very concerned about its own territory like all other large predators (**40 km^2** for each male and **12 km^2** for each female). The territory of each female is used for her own exclusive walking purpose enjoying enough space and also in search of food for herself and her cubs. The territory of a male sometimes superimposes the territories of several females where he alone mates with each of them. Marking of the boundaries of tiger's territories represents a very fascinating behavioral manifestations which is done in a number of ways to make it a confirm message to other tigers of the same sex in order to prohibit them from intruding and entering into the occupied area. This marking takes place by spraying of urine on the tree trunks or other vegetation about **3** ft above the ground and sometimes on the underside of a leaning tree trunk to make sure not to be washed away by the rain. Everywhere, the odor of the urines may still be detectable as long as 3 weeks after spraying. Besides, tigers claw the bark of trees and the soils of hard texture to develop visual signs of their presence. Marking territory boundaries helps to avoid conflicts for sharing food and mates and thereby prevents unnecessary fights (**Fig.** 4.7).

Tigers, being the most magnificent and best known wild animals, are very essential for the forest ecosystem, as are their prey – the wild pigs and deers. **Tiger** (*Panthera tigris tigris*) is a gracious carnivore found in the different forest tracts of central India (Uttar Pradesh and Madhya Pradesh) from the Himalayas to the Vindhyachal ranges. In **1970**, the tiger population was only **1540** which as per very recent estimation by the Government of India has figured around **2967**. To save tiger from extinction, "**Project Tiger**" was launched in India in the year **1972**. Since then, the tiger population has been slowly but steadily increasing. Tigers essentially live in the forest, as are their prey – the wild pig and deer. Once deprived of having their suitability, a territory of about **40 km^2**, they are doomed and lead to human–tiger conflicts. The Indian Government through the state forest and wildlife department, after being advised by the Indian Board for Wildlife and the **World Wildlife Fund (WWF)**, conducted several surveys on the population estimates of the tiger and recommended for the creation of several biosphere reserves, national parks, and Project Tiger for the conservation of this wonder animals of the world. Throughout Asia, where the other seven races or subspecies of tiger occurred, marked decline of this wild beast has occurred. The Caspian and Balinese races were already extinct. Only five Javan tigers remained. In some parts of India, tribal people have lived for centuries in forests where tigers were numerous and where there are still sufficient wild pigs and deers to satisfy the tigers, thereby maintaining their habitats to remain intact and reducing the outbreaks of man-killing activities. In fact, the tribal villagers often behave in a casual manner without paying any serious concern for the prospective attacks of the tigers keeping their distance merely by shouting or beating tin cans. Neither sides, the local peoples residing in the periphery of the tiger habitat and the tigers roaming in their territory in the forests do not make any attempt to encroach the territory of the other and thereby share the forest-derived benefit in a state of watchful harmony. The tigers are not inherent man killers and in normal circumstances go out of their way to avoid humans. In some parts of India, where local forest-dwelling peoples mostly lived for centuries in forests where tigers were present in higher numbers along with sufficient numbers of wild pigs and deers in order to satisfy the need of tigers, outbreaks of tiger killing very rarely occurred as their habitats remained intact (**Fig. 4.7**).

India has a variety of well-known large-sized cats and other carnivores. These are as follows:

4.14.3.4.1.2 Asiatic Lion ***(Panthera leo persica)***

A small remnant population of Asiatic lions still survives in the Gir National Park in the Indian state of Gujarat. They closely resemble the African lion from which they originated, though the males usually have somewhat less heavy manes. As per interpretation of a noted wildlife expert, E. P. Gee, the difference is probably not a natural evolutionary change but the result of the selective hunting. The range of the Asiatic lion once extended from Greece through the Middle East to central India; their world population stood at only **177** in the year **1977** and is declining. The Gir Forest had been the property of the Muslim rulers, the Nawabs of Junagadh, who had protected the lions since early in this century. When the last Nawab fled to Pakistan after the partition of India, the land was speedily overrun by villagers and their cattle. Nearly all the deer had vanished, and the lions were obliged to feed on the thousands of domestic cattle, which were rapidly destroying the vegetation. Skilled eco-management of the Gir National Park has made it one of the best managed wildlife reserves in India. With the recovery of grazing areas, the population of various deer species has increased considerably during the last few decades sustaining the life of lions by providing suitable prey foods (**Fig. 4.7**).

4.14.3.4.1.3 Cheetah ***(Acinonyx jubatus venaticus)****: An Extinct Wildcat from India*

One of the fastest predators in India, cheetah became extinct in India. This efficient predator among the big cats is very unique in having strong body build with flexibility because of possession of sinewy legs, a deep chest, and a comparatively small head. Cheetah is taller than any other leopards and possesses black tearline running from the eye to the upper lip and also semiretractible claw. It was found in central India, Deccan Region, and the Thar Desert up to Jaipur in Rajas. It is one of the most beautiful, agile, and fastest animals. Unfortunately, it is regarded as an extinct species in India. Cheetah was last reported in the Deccan in central India in **1920** (**Fig. 4.1**).

4.14.3.4.1.4 Leopards

Out of the three species of leopards (leopard, snow leopard, and clouded leopard) (**Fig. 4.8**), only leopard is occasionally seen in the Gangetic Plain and its associated riverine forest tracts. Leopards prefer to live in tropical deciduous forests preying upon deers, boars and pigs, rabbits, rodents, monkeys, fish, birds, snakes, and domestic animals as their foods. Being the very efficient climbers and swimmers, they defend their territories all year round, making the boundaries with urine and scrapes on tree trunks. Leopards are mostly solitary and nocturnal hunters. Leopard litters of **1–3** cubs are born about 4 months after mating. After passing about **3** months in the hidden shelter, mostly in the deeper part of the forest, the grown-up cubs start to accompany their mother on hunting forays and also to learn defending themselves from the attacks of predators such as tigers, hyenas, and wild dogs. At **22** months, the youngs leave to find their own territory.

4.14.3.4.1.4.1 Common Leopard ***(Panthera pardus)***

The **common leopard (*Panthera pardus*)** is the largest among all other members of the cat family and characterized by yellow coat marked with black rosettes band while coated underside (**Fig. 4.8**). The large eyes are always forwardly projected. The color of the back of the ear is black with a white spot in the center. They are able to coexist with tigers preying smaller preys. Chital and langur monkeys appeared to be the main prey species of the leopard in the study area.

On examining leopard droppings, several prey items, expressed as percent of occurrence, have been noted chital (**59%**), langur (**27%**), porcupine (**9%**), sambar (**9%**), and barasingha (**4.5%**). It is the smaller spotted cousin of tiger. It can live in all types of forests. Once it was widely distributed in the country, but its number came down drastically low due to overhunting.

*4.14.3.4.1.4.2 The Snow Leopard **(Panthera uncia)***

One of the relatives of common leopards, the beautiful snow leopard, is characterized by magnificent creamy white fur with large dark rosettes (**Fig. 4.8**). It has a creamy gray coat with large black rings. Snow leopard, also called ounce, is found in the mountain ranges of South and Central Asia and seldom seen with the least chance of spotting as they prefer to reside in the coniferous forest about an altitude of **12, 000 ft** up to but sometimes descends down to mountain valleys with an altitude of **6000 ft** in search of their preys or even more down to the valleys of **1000 ft** altitude to avoid the harsh winter. They adapt in the snow-covered areas. The color of their bodies is smoky gray with lot of black spots on the legs and face. Their paws are massive in comparison to the size of their bodies. A snow leopard has a cushion of hair on the underside of its paws which not only keeps its feet warm but also enables to run across without sinking in too deep to outrun its prey. The territory of snow leopard may be expanded up to **40 km^2** to undertake effective hunting during the period of scarcity of food. A snow leopard also dies for its beauty as they are very much prone to poaching because of their very costly furs which are used by the mountain peoples as their long thick, beautifully marked overcoat. It is found high in the Himalayas from Kashmir to Sikkim new snow line. This magnificent wild beast is currently listed as vulnerable on the **IUCN** Red List.

*4.14.3.4.1.4.3 Black Leopard or Panther **(Panthera pardus)**: Melanistic*

The three leopard species, however, still survive, but only the common leopard, which is particularly adaptable creature, has maintained its original range. Usually called the panther in India, it not infrequently occurs in an all-black form, through which the typical "**rosette**" markings are still visible in sunlight. The so-called black panther is not, however, a true species but a morph or a color phase of the leopard. It is the melanistic color variant of any *Panthera*, particularly of the leopard (*P. pardus*). It is thought that melanism confers a selective advantage under certain conditions since it is more common in regions of defense forest, where light levels are lower. They are found in densely forested areas of Assam and other northeastern parts of India and also in some parts of southern India (**Fig. 4.8**).

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The different small cats that are found in India are as follows:

4.14.3.4.1.4.4 Clouded Leopard ***(Neofelis nebulosa)***

Clouded leopards, by contrast, are strictly arboreal tropical species, whose range is from southern Nepal eastwards to China. Owing to the presence of short legs and very long canine teeth, the physical appearance of this sometimes is confused with the miniature saber-toothed tigers. Their grayish buff coats are heavily mottled with blackish blotches, and they have abnormally long tails (**Fig.** 4.9). They have wide range of distribution in the Himalayan foothills of Southeast Asia, including in the subtropical forests in the northeastern Indian states and even extended to China. They predate on deers, small-sized apes and monkeys, hares, and porcupines. The clouded leopard is listed as vulnerable on the **IUCN** Red List.

4.14.3.4.1.5 Pallas' Cat ***(Otocolobus manul)***

Of the six small cats, the strikingly long-haired Pallas' cat of Tibet and Ladakh is rarely seen, though their skins appear occasionally in native markets. The furs on the face are gray in color, while the color of long furs in other parts of the body which is silvery gray gives this small wildcat a shaggy appearance. It has been distinctively flattened head and ears and hunts small rodents on high rocky ground. The thick and proportionately long tail is broadly ringed with black-colored terminal part. This very rare cat species is characterized by having broad head and short well-separated small ears (**Fig. 4.10**). This Central Asian species are occasionally seen in the Ladakh areas of India. This very timid and lazy member of cat family resides in the holes of rocks and preys on small birds and mammals.

4.14.3.4.1.6 Caracal ***(Caracal caracal)***

This nocturnal species is distinguished by long legs and long tufted ears on comparatively short face. It is a pale brick-colored, proportionately tall and slender cat with black ears with ear tufts. Its legs are longer, and the color of the back of its ear is black with ear tufts reaching up to **5** cm in length (**Fig.** 4.3). Its tail is proportionately longer (about **12–14** inches) representing about half of the body length. It is marked by the presence of two vertical bars by the side of the eyes and also one dark spot on each side of the upper lip (**Fig. 4.10**). They prefer to inhabit in the bushy scrubland and also in grasslands in between forest and rural human settlements in the arid and semiarid climatic condition. These endangered animals mostly prey on birds and small mammals. This species is native in India, Middle East, and Central Asia and Africa.

4.14.3.4.1.7 Eurasian Lynx ***(Lynx lynx)***

It is a medium-sized (length is in between **3** and **4** feet, and height is around **2** feet) member of the cat family and possesses very short tail (around **8** inches) (**Fig. 4.10**). It has a sandy gray coat with innumerable number of spots. The tips of both the ears are provided with long black tufts. It mainly inhabits in the boreal forest in an altitude of **5000** feet. Variety of small mammals and birds (hares, jungle fowls, pheasants, juveniles of deer families, etc.) are preyed by this animal. This species is native to the Himalayas, Central Asia, Siberia, the Tibetan Plateau, and Central, Eastern, and Northern Europe. It is currently listed as least concern by the **IUCN**.

4.14.3.4.1.8 Golden or Temminck's Cat ***(Catopuma temmincki)***

Golden cat attains a length of well over a meter with its unmarked tawny coat with colors ranging from golden brown to creamy while. It is said to occur in Assam, Nepal, Sikkim, and the Hill tracts eastwards through Burma and Malaysia. This medium-sized (little more than **3** feet) wildcat is characterized by golden coat covering which becomes fragmented by a distinct white strip over the body, and the two eyes are also lined by two white stripes. The golden brown to dark brown mixed up with broad white stripes. The newly born kittens are covered with black but comparative long coats (**Fig. 4.9**). It can climb well and haunt rodents, hares, small-sized angulates, and birds. It is a vulnerable species as per the Red List of the **IUCN**.

4.14.3.4.1.9 Leopard Cat ***(Prionailurus bengalensis)***

It is the most common small cat characterized by leaner appearance and long legs, brownish buff on the body coat, and the presence of two black streaks between the eyes and ears. Two other species, the pale buff, round-spotted leopard cat and the more heavily blotched marbled cat, which resembles a miniature clouded leopard in its markings, inhabit the Himalayan forests. A few of the former are also found in southern India, while the latter is chiefly restricted to the northeast. Both, although now legally protected, are heavily exploited by poachers for their beautifully marked skins. This species is distributed in the South and Southeast Asia including India, China, and even Russia. Food items of this species include amphibians, reptiles, birds, insects, and small mammals (**Fig. 4.8**).

4.14.3.4.1.10 Fishing Cat ***(Prionailurus viverrinus)***

Out of six small cats, two (jungle cat and fishing cat) are still found in different marshy and swampy riparian habitats of riverine networks of Indo-Gangetic Plain of the states of Odisha and West Bengal of eastern India. They are all intermediate in size between the former and domestic cats. The largest of the group is the fishing cat, which has a rough, grayish-tawny coat with rows of diffuse dark streaks and rather short legs. The face of fishing cat is longer, its eyes are closer together, and its face is thicker and shorter, reaching only to the cat's heel when it is standing. The hunting skills of this animal deserve special mention as they wait patiently by the side of the water body with an aim to reach right timing for hunting action, and just getting the same, the cat suddenly hurls itself into the water with a loud splash. Moments later, it is seen to float on the surface of the water with a flapping fish clamped between its jaws. The cat aptly derives its name as the "**fishing cat**," because of its look after following the hunting action dripping wet from the head to foot. This very energetic wild animal clambers onto the river bank, shakes itself, and settles in a secluded spot to demolish its meal. Their swimming or paddling activities immersing the body up to its neck and solidly built turn the fishing cat completely at home in water. It is also provided with slightly webbed feet with retractile claws on its short and muscular legs. Besides, the coat of its body is waterproof as the layer of dense fur next to its skin is kept dry by another layer of longer, coarser fur on the outside. In times of drought, a fishing cat preys upon mice, lizards, and birds, and during the adverse period with scarcity of foods, the fishing cats with its fearless attitude can kill a prey as large as young goats, eagles, and dogs. Although this cat species is discontinuously distributed across South and Southeast Asia, in India, it prefers to inhabit in the red beds and jungles in the Indo-Gangetic Plain, mostly in the eastern India (West Bengal, Odisha, Bihar, Jharkhand, and Chhattisgarh). The fishing cat is currently listed as endangered by the **IUCN**.

*4.14.3.4.1.11 Jungle Cat **(Felis chaus)***

It is gray brown in color with faint red stripes running across the forehead and on the outer surface of the legs. Its eyes are encircled with white rings and with a dark tear stripe running down each cheek. In India, this species of cat is found mostly from the forest tracts of the Himalayas to the Cape Comorin. It prefers bushy forests with scrubland along the water bodies and preys upon small animals (rodents, birds, hares, fish, amphibians, and also insects) hunting during night. This cat is medium-sized with long legs and short tail. The tails are provided with few black rings near the distal end (**Fig. 4.3**). Jungle cats are little bit larger in size than the house cats and act as potential predators on chital fawns. Although fairly common in the park, they were infrequently seen in the wild except during the cool season, when they congregated on the meadow apparently while mating. All of the **27** droppings collected contained the hair and bones of rats and mice and in two instances also the remains of a lizard. This species is having a wide range of distribution in the Southeast Asia, the Middle East, the Indian subcontinent, and southern China. This species is listed as least concern on the **IUCN** Red List.

*4.14.3.4.1.12 Marbled Cat **(Pardofelis marmorata)***

It resembles a miniature of clouded leopard and mainly inhabit in the Himalayan forests at an altitude of about **8000** feet. This gray to pale red-colored cat has long canines, rounder skull, a tail equal to the size of the body, and patches all over the body. They are usually very selective nocturnal animals preying mainly on rodents, lizards, and small birds and rarely encountered by man in the wild. This species is listed as near threatened on the **IUCN** Red List.

4.14.3.4.1.13 Indian Desert Cat ***(Felis silvestris ornata)***

This wildcat species, also known as Asian steppe wildcat, attains a size little more than a domestic cat but with a comparatively long tail, the terminal part of which is ornamented with black rings **(Fig. 4.8)**. The body color of the coat varies from deep to pale yellowish, marked by small black spots. It restricts its abundance mainly in the scrublands near the forest belts and low-lying deserts or semidesert areas of central and western India. They are found from the southern Mongolia, western China, and the eastern Caspian Sea region. Small birds, lizards, and insects constitute their food materials. The desert cat is currently listed as the least concern on the **IUCN** Red List.

4.14.3.4.1.14 Rusty-Spotted Cat ***(Prionailurus rubiginosus)***

This smallest cat of the world having the size less than **1** foot is characterized by silvery gray-colored soft and smooth body coat ornamented with dark brown spots, the sizes of which are gradually reduced from the anterior to posterior direction. The small-sized posteriorly curved tail is uniformly colored. Both the small rounded ears are marked with a large pale spot. The forehead of this cat is provided with two longitudinal white stripes, and both the eyes are encircled by white rings. This cat prefers to inhabit in the scrublands and grasslands in between the large forests and human habitations from where they procure their food (birds, rodents, frogs, insects, and lizards). This species is occasionally encountered in the western and central India. This species is listed as near threatened on the **IUCN** Red List.

4.14.3.4.1.15 Asiatic Wildcat or Indian desert cat ***(Felis silvestris)***

This small (little more than 1 foot) species resembles very closely to the domesticated cats but differs by possessing robust built, black spots all over pale yellow-colored body and whitish ventral side. Its tail is comparatively long with black-colored terminal part. The middle parts of both of the forelimbs are marked by black markings. It mostly prefers to live within burrows. It is distributed in the arid and semiarid eco-regions of central and western India.

4.14.3.4.2 **Wildlife Belonging to Dog Family (Fig. 4.11)**

*4.14.3.4.2.1 Wolf: An Important Wildlife in the Riparian Forest (**Fig.** 4.11)*

The Indian Wolf is recognized as a distinct subspecies *Canis lupus pallipes*, being smaller and shorter-haired than its larger cousins inhabiting the tundra and boreal forest zones of North America and Eurasia. There is, however, a much larger race *C. lupus chanco* inhabiting the inner Himalayan regions and Tibet. Around **50** years back, wolves were seen in higher abundances in the drier open plains and desert zones of peninsular and northwestern India. The increase in human population and spread of cultivated areas by way of destroying their habitats have led to a rapid decline in the numbers of these animals, and the accelerated attacks by man against this animal impose threats to the flocks of domestic stock. Wolves are found in sparse population in those regions such as in Rajasthan, Ladakh, Gujrat, and Bihar, and in these areas, they roam over large territories, often hunting small family parties until the young becomes independent.

Wolves cannot tolerate constant human disturbance, but in the areas where they do survive, they are not particularly shy of mankind and will often stand and stare at the human intruder before loping off. They usually hunt in late afternoon and early morning as well as throughout the hours of darkness, traversing distances up to **20** kilometers in a night. By daytime, they take shelter in natural rock caves or in burrows which they are capable of excavating themselves. The youngs are born in an underground nest chamber, and litter sizes were seen to vary from **3** to **9** pups which being blind and helpless at birth take about **8** weeks to be weaned. The gestation period is around **68** days and females breed only once a year. The eyes of pups get open after **1** week of their birth, and **3** weeks thereafter they emerge out from the den accompanying their mother. A cave or rock crevice is used as den where they spend about **10** weeks of their age. The other members of the pack used to feed them on regurgitated food materials until they are big enough to travel and hunt their preys which include jungle fowls, deers, hares, beavers, and even insects. In the north-western part of India and in the plains of Pakistan, most litters are produced in late winter and early spring. In the Himalayas, cubs are born in spring or early summer. In captivity, they have lived for **15** years. Wolves have become very scarce in India, but they can be seen in the barren highlands of Kashmir and deserts of Rajasthan.

*4.14.3.4.2.2 Fox (**Vulpes bengalensis**): A Very Common Wild Fauna of Forests and Scrublands*

Nine (**9**) species of foxes belonging to the genus *Vulpes* have been recorded from the different zoogeographical realms of the globe. Out of the five species which occur in the Indian subcontinent, two, the red fox (*Vulpes vulpes*) and the Indian fox (*Vulpes bengalensis*), are widespread in their distribution through the length and breadth of the country. The Indian fox is characterized by having a black spot at the tip of its tail and slimmer in build with rufous legs, and the back of ears are with least darkness. An adult Indian fox weighs around **4 kgs** with a length of the body around 3 feet. This very so-called clever wild mammal hunts independently not enjoying a gregarious life, and most species are thought to be monogamous forming stable pair bonds. Being an omnivore in food habit, they subsist on different category of food items, ranging from wild fruits such as *Ziziphus* in the winter seasons along with several available insects, small birds, and rodents. The red fox produces **4** to **6** pups during the late winter or early spring, which are born blind and relatively helpless in a nest chamber excavated in a burrow. The cubs are feed upon regurgitated food brought by mouth parents for the first few weeks of their lives. They emerge at **5** weeks and then spend a good deal of time playing outside their den in the early morning and evening. They are independent in hunting by about **5** months of age.

4.14.3.4.2.3 Jackal ***(Canis aureus)****: A Very Common Wild Fauna Along Riverine Tracts*

Being among the most common wildlife in the periphery of rural surroundings in India, the jackal, with a body length of around **4** feet and a height of around **2** feet, is characterized by having a bushy tail, light brown-colored head, and the lack of elevated forehead. The adult jackals were usually seen singly or in pairs, sometimes accompanied by their young, as they trotted along the meadow roads.

On analyzing the feces of jackal, food contents of this animal reveal more than two-thirds of the hair and bones of rodents which belong to the species *Rattus blanfordi* (Thomas), *Rattus rattus narbadai* (Hinton), *Rattus rattus rufescens* (Gray), *Golunda ellioti ellioti* (J. Gray), *Mus booduga booduga* (J. Gray), *Mus muscrulus homoorus* (Hodgson), and *Vandelenria oleracea oleracea* (Bennett). Jackals hardly prey upon hares and other small mammals in the area, such as musk shrew, palm squirrel, and mouse deer. However, domestic chickens constitute the favorite prey of the jackals, and common fishes in the nearby streams and rivers fish are either caught or scavenged, as revealed also by the presence of scales and bones of fishes in the droppings. The remains of reptiles, most frequently lizards (*Calotes versicolor*, *Mabuya dissimilis*, *Mabuya macularia*, *Mabuya carinata*, *Lygosoma maculatum*, and *Riopa albopunctata*), were seen in plenty in the feces. Moreover, the remains of ungulates, both domestic and wild, are present in only about **4%** of the feces. Jackals tend to approach a killed prey several times with close observation before starting their feast reflecting their nervous attitudes. Vegetable matters especially the remains of fruits are observed in substantial amounts (**25%**) in the feces principally contributed by *Ziziphus* fruit and village garbage.

4.14.3.4.2.4 Striped Hyena ***(Hyaena hyaena)****: An Important Medium-Sized Carnivore*

This medium-sized (the maximum length of the body is little less than **4** feet) wild carnivore is a digitigrade animal with very strong slightly curved nonretractile claws. It has very strong body with broad head, massive jaws endowed with premolar teeth rest on strong and stout legs, and the forelegs are much longer than the hind bones, making its slouched appearance. They are distributed in the arid and semiarid tracts avoiding dense forest, mostly in the scrubs and dry thorny small forests in the western India. This species becomes very active in foraging and eats almost any flesh, including fish, tortoises, and small herbivores mostly during dry season. Hyena may be a solitary hunter or hunt in groups. It requires not less than **1** year to grow up to become mature and start breeding when they are **2** or **3** years old. The mother nurtures the litter of two to three newly born youngs coated with wooly brown furs and suckles them for **12** months or more.

*4.14.3.4.2.5 Spotted Hyena **(Crocuta crocuta)***

The spotted hyena, popularly known as laughing hyena, is found in higher abundance covering a wide range of habitats (forests, savannas, scrublands, etc.) in sub-Saharan Africa. Being the largest known member of the family Hyaenidae, it had its origin from Asia and differs from its Asian counterpart by its stooping posture with bear-like build and almost circular ears (**Fig. 4.11**). Besides, females are devoid of external vaginal opening but possess psedo-penis. The success of survivability of this species has been attributed by its ability of hunting, power of scavenging, and intelligence for opportunism.

*4.14.3.4.2.6 Wild Dog **(Cuon alpinus)**: An Important Medium-Sized Carnivore*

Indian wild dogs attain a size in between the wolf and jackal but differ from both of them by having six molar teeth in the lower jaw instead of seven as possessed by others. It has a paler red coat of hairs over the dorsal side, almost elliptical ears, stout but short legs, and a bushy tail with black spot on the terminal part. Although this wild fauna can sometimes be spotted singly, they maintain a gregarious mode of life during haunting on preys such as different members of deer family, pigs, wild sheep, goats, antelope, etc. Its breeding season is winter and the female produces **four** to **six** pups at a time.

4.14.3.4.3 Carnivores Other than Cats and Dog Family

*4.14.3.4.3.1 Civets **(Viverra zibetha, Viverricula indica)***

Civets are medium-sized (**around 3 feet**), strongly built animals with conical protruded head and laterally compressed body with short thick legs. A long elevated crest covered by black-colored hairs lies over the body extending from the middle to the terminal portion of the body.

Villagers in India are accustomed with the presence of civets (mostly solitary easily tamed carnivore). Out of the six different civet species, the largest one is the *Viverra zibetha*, whereas the smallest civet species is *Viverricula indica* which is very common throughout India. They are readily recognized by their boldly banded tails, sinuous bodies, short legs, and pointed short muzzles (**Fig. 4.11**). They inhabit a variety of habitats ranging from the foot hills of mountains with bamboo forests to the scrublands on the riverine banks.

*4.14.3.4.3.2 Common Palm Civet **(Paradoxurus hermaphroditus)***

The long slender body measuring a length of little more than **2** feet is covered by brownish black furs (**Fig. 4.11**). Three longitudinal stripes are present over its body running from the head to tail. This arboreal nocturnal omnivore alongside feeding fruits also lifts poultry birds. They are found throughout non-Himalayan India, except the arid deserts.

4.14.3.4.3.3 The Himalayan Palm Civet ***(Paguma larvata)***

This small-sized (around **2** feet) civet can be differentiated from other civets found in India by the presence of white whiskers and absence of spots over the body. The dark patch over the face is split by the grayish white line down to the forehead. The tail is comparatively long endowed with thick gray-colored furs with the presence of black patch at the terminal part. This civet occurs mainly in the Himalayan mountain of Jammu and Kashmir and also in the northeastern parts of India.

4.14.3.4.4 *Binturong* ***(Arctictis binturong)***

This largest civet (more than **3** feet) can be distinguished from other members by possessing tufted ears and blackish gray-colored body covered by long shaggy coat giving the look like a bear. The tail is muscular and attains a length almost equals to that of the length of the body. This arboreal animal restricts its distribution in the northeast parts of India.

4.14.3.4.5 Gray Mongoose ***(Herpestes edwardsii)***

These animals are characterized by their agility and nonstop activity and are represented **by six species** in India, of which the common **gray mongoose (*Herpestes edwardsii*)** are widely seen both as wild and domesticated animal. This mongoose species attains a size of nearer to **2** feet with a tail of about the same length of the main body. The color of the body is gray throughout only with whitish yellow patch at the terminal part of the tail. The small Indian mongoose (*Herpestes auropunctatus*), half of the size of the gray mongoose, remains active and hunts at daytime. The four other much less common species are the stripe-necked of the Western Ghats, the brown of southern India, the ruddy mongoose of peninsular India, and the interesting crab-eating mongoose of Nepal and Assam. The last-mentioned species is the only aquatic member of the family, who can swim and dive to catch fishes (**Fig.** 4.17).

4.14.3.4.6 Smooth-Coated Otter ***(Lutra perspicillata)***

Otters are aquatic carnivores mainly depend for their diets of fish and invertebrates (**Fig.** 4.17). India is a home of **3** out of the **13** species of otters found worldwide. These are Eurasian otter (*Lutra lutra*), smooth-coated otter (*Lutra perspicillata*), and small-clawed otter (*Aonyx cinereus*). But the common otter and small-clawed otter are restricted to the Himalayas, whereas smooth-coated otter are uniformly distributed throughout the length and breadth of India especially along the riverine basins of the River Ganges. Smooth-coated otter represents the most common otter of India, the body of which is covered by gray–brown furs. Adult of this otter gains maximum weight of **8 k**g and a body length of little more than **2** feet. They are strong and agile swimmers. They breed any time during summer and are nocturnal feeders, feeding on mainly fish. They groom their coats a lot to keep them sleek and waterproof. The male mates a number of females along a stretch of a river and plays little no part for rearing the youngsters. Usually, female otters have only one litter a year.

4.14.3.4.7 **Bears: A Distinctive Group of Carnivore of Riparian Forest**

This particular group of wild fauna has ten different species distributed in four different continents except in Australia, Africa, and Antarctic continents. They are very unique in shape and posture with relatively huge broad heads with small eye and a short stumpy tails almost hidden within the body fur. Three species of bears (the brown bear, the Himalayan black bear, and the sloth bear) are found to occur in Indian forest tracts which are always in conflict with man and are therefore subjected to their death.

*4.14.3.4.7.1 Sloth Bear (**Melursus ursinus**): The Most Prevalent Species in Tropical Forest*

The sloth bear is a medium-sized bear, having a length of **150** cm and body weight of about **200** pounds, with a long, shaggy, black coat and a white crescent of hair on the chest (**Fig. 4.18**). This omnivorous animal lives mostly on fruits, honey, and insects. It sucks up white ants from the hills which they break with the help of their claws. The movements of this wild animal follow seasonality and become very active primarily during the hot season when several kinds of fruit ripened there and came down into the valleys. Examination of droppings of this animal shows the seeds and other remains of the fruits like *Ficus*, *Ziziphus*, *Syzygium*, *Cassia*, etc. at different periods of the year. Although fruits constitute an important part of the bear's diet from April to June, termites are its staple food for the rest of the year. Owing to its strong likings to the fleshy petaled flowers of mahua fruit plants (*Madhuca longifolia*), it often can climb up the top of the trees in search of flowers and also insects.

*4.14.3.4.7.2 Black Himalayan Beer (**Selenarctos tibetanus**)*

It is larger than the sloth bear. It is carnivorous and has V-shaped white mark on the chest (**Fig. 4.18**). **The black bear** is still fairly numerous in the Himalayas, occasionally as high as tree line (**3700** meters) but more often at lower altitudes. They prefer to inhabit in broad-leaved deciduous and coniferous forest in the Himalayan mountain, but in the northeast, they have extended their range down into the tropical forests of Bangladesh and Assam, India. **Black bears** hibernate during the coldest part of the winter, in leaf-lined rock or earth caves. When they descend to the foothills in search of fruit, they are frequently disturbed by woodcutters and farmers, whom they attack without hesitation by hugging and biting the face if at close quarters, leaving terrible wounds caused by its raking claws.

4.14.3.4.7.3 Malayan Brown Bear ***(Helarctos arctos isabellinus)***

The range of the **brown bear** is only just within the region, **at high altitudes** in the northwestern and central Himalayas, being most numerous in Ladakh. In summer, it descends below the tree line and, if food is scare, plays havoc with domestic flocks, although its usual diet is fruit, roots, and rodents. It is heavier than Himalayan black bear and is wrapped with thick brown-colored fur. It resides in the grass belts above the tree lines at high altitude nearer to the snow. It hibernates in winter, mates during summer, and produces two cubs which are born after the retreat of the winter.

4.14.3.4.8 Red Panda ***(Ailurus fulgens)***

In the evolution of mammals, the phylogenetic status of panda is very much debatable. In its build and walk, the giant panda resembles a bear, but the much smaller red panda looks (*Ailurus fulgens*) face the threats of extinction not only because of the anthropogenic reasons but also due to the inherited biological cause where the mother will rear only one offspring, leaving others to die. The surviving one becomes mature and independent at a year old. This colorful attractive arboreal wild fauna is characterized by a rounded head, cone-shaped erected ears, stumpy muzzle, and hairy legs endowed with retractile claws (**Fig. 4.18**). It relies on are fibrous and largely indigestible, giving little nourishment; it devotes much of its solitary life to eating. Its jaws are powerfully developed to manage all its chewing. It is distributed from the Himalayas of northern West Bengal to the southern China through the forest tracts of the State of Sikkim, India, and Nepal.

4.14.3.4.9 **Indian Wild Boar (*Sus scrofa affinis)***

It is a widely distributed ungulates in the mixed deciduous forest tracts enjoying all kinds of habitats such as scrub and grasslands along the Ganges and Godavari riverine plains in India. It has a short muzzle with the orientation of snout almost perpendicular with the head (**Fig.** 4.18). The body portion behind the shoulder blades rises like a hump, and the neck is proportionately very short. The body is mainly covered with brown fur tinged with black hairs. The wild boar as fearless, savage, and dangerous wild animal live free in their native habitats and move with ease and at considerable speed through the thickest undergrowth. The head and body of this sturdy animal look like two cones, joined together at the base and flattened at the sides. Their very long muzzles end up in a sensitive, mobile snout with large nostrils which are used not only for raking over dead leaves but also for digging the earth materials in search of roots, bulbs, fungi, and small animals. The canines of both the jaws grow to form long triangular and upcurved tusks for defense and digging roots.

The wild boar or pig is omnivorous. It feeds on carrion, snakes, insects, roots, tubers, and cultivated crops. It is gregarious living in families in grass or bush of marshy places but is now rare. The rooting habit of the wild boar – using its flexible snout to root out edible substances from below ground – is undoubtedly of considerable importance in the forest's ecology. These busy digging activities aerate the soil in much of the same way as does a plough, creating conditions favoring the germination and development of new plants, and consequently the mammal performs a positive roles in stimulating forest growth.

4.14.3.4.10 **Pigmy Hog *(Sus salvanius)***

This small-sized (maximum length is around **2** feet and height is little more than **1** foot) wild pig is characterized by much shorter snout and tail. The length of the brownish- to black-colored hairs on the body is not uniform in length with the presence of longer hairs in the hinder portion of the neck (**Fig. 4.18**). Living with a party of **5** to **15**, they prefer to forage during night dislodging the soils in search of roots and bulbs of the plants and also predate the eggs of birds, lizards, insects, etc. Wild pigs represent a considerable economic problem because of their devastation of crops, but their numbers remain under control by other carnivores. It is a widely distributed ungulates in the forest tracts throughout India except the high altitude of the Himalayas and arid zones of Rajasthan and Gujrat.

4.14.3.5 Rodents: The Burrowing Animals with Fossorial Adaptation

Many rodents dig burrows in the ground; some, such as beavers and musk rats, are partially water-dwelling. Others live in trees, and there are no flying rodents; some of the squirrels can glide long distances using webs of the skin between their limbs and trunks.

All rodents have characteristic teeth, including a single pair of razor-sharp incisors. With these teeth, the rodent can gnaw through the toughest of husks, pods, and shells to reach the nutritious food contained within. Gnawing is facilitated by a sizable gap, known as the diastema, immediately behind the incisors, into which the lips can be drawn, so sealing off the mouth from inedible fragments dislodged by the incisors. Rodents have no canine teeth, but they do possess a substantial battery of molar teeth by which all food is finely ground. Most rodents are squat, compact creatures with short limbs and a tail. Rodents have influenced history and human endeavor more than any other group of mammals.

Many of the species under the order Rodentia act as important mammalian pests consuming prodigious quantities of carefully stored food and also are supposed to spread fatal diseases. However, many species of this kind play beneficial roles for the human beings in general and ecosystem in particular in maintaining the relationship between plants and fungi. Many fungi form mycorrhizal (mutually beneficial) associations with the roots of plants that increase the ability of plants to extract nutrients and water from the soil by many thousands of times. So important is this relationship that many plants simply cannot survive without the fungi and vice-versa. One of the most important groups of fungi is the truffles which are related to mushrooms but form their fruiting bodies underground. Truffles and truffle-like fungi rely on animals to dig up the fruiting bodies and to disperse the spores, either in the wind or in the animal's feces after eating the fungus. When gaps form in forests, for example, small mammals deposit fungal spores in their feces in the gaps, thereby bringing the fungi to the places where plant seeds are germinating. In the forests, it is believed that this three-sided relationship between plants, fungi, and small mammals including rodents is vital for the ecosystem.

Rodents occur in virtually every habitat, from the high arctic tundra, where they live and breed under the snow (lemmings), to the hottest and driest deserts (gerbils). Others glide from tree to tree (flying squirrels), seldom coming down to the ground or else spend their entire lives in underground networks of burrows (mole rats), often undertaking complex engineering programs to regulate water levels (beavers), while others never touch a drop of water throughout their entire lives (gundis). Such species can derive their water requirements from fat reserves.

4.14.3.5.1 Classificatory Scheme for the Order Rodentia

The term rodent derives from the Latin verb *rodre*, which means "**to gnaw**." Over **42%** of all mammal species belong to this one order, whose members live in almost every habitat, often in close association with humans. Modern taxonomists divide Rodentia into two suborders: Sciurognathi (squirrel, mouse) and Hystricognathi (porcupine, cavy). Order Rodentia includes **28** families, **435** genera, and **1999** species. Suborder Sciurognathi (squirrel-like rodents, squirrels, beavers, etc.) has **284** species in **56** genera in **5** families. Mouse-like rodents (rats, mice, hamsters, lemmings, etc.) has **1480** species in **316** genera in **5** families. Suborder Hystricognathi (cavy-like rodents such as porcupines, cavies, octodonts, dassie rat) has **235** species in **63** genera in **18** families.

4.14.3.5.1.1 Squirrels

Four different categories of squirrels, **viz.**, giant squirrels, flying squirrels, Himalayan squirrels, and striped squirrels, are found to occur in India. A considerable number of beautifully colored squirrels and flying squirrels inhabit in the forests of eastern India. They glide from trees to trees for quite astonishing distances of with the help of the extended membranes between their wrists and ankles, looking like flying tea trays.

*4.14.3.5.1.1.1 Indian Giant Squirrel **(Ratufa indica)***

Out of the four species of giant squirrels in Asian subcontinent, the very common one is the Indian or Malabar giant squirrel which is a multicolored attractive arboreal Rodentia, with maroon and black combination of colors of their coats on the dorsal part of the posterior regions of the body, whereas the underparts are covered with whitish creamy colors. It has a length of little less than 3 feet with a maximum weight of little more than 2 kg. They are true tree-dwellers and rarely come down to the floor of the forest. They build round-shaped nests at the higher tiers of the large trees (**Fig. 4.17**). They remain very active at night and also in the early morning, spending most of their daytime taking shelter within the nests. They are very common in the tropical deciduous forests in the states of Odisha, Madhya Pradesh, Jharkhand, and Andhra Pradesh, India.

*4.14.3.5.1.1.2 Indian Giant Flying Squirrel **(Petaurista philippensis)***

The body coats of this flying squirrel are grayish brown in color, whereas the color of the ventral side becomes paler. The ears are distinguished by the presence of reddish brown margins. The patagium, a flexible muscular flap covered by the skin stretched in between the wrist and the ankles, is used for gliding. This squirrel species is having a very wide range of distribution in the deciduous and evergreen tropical forests throughout India.

*4.14.3.5.1.1.3 Northern Palm Squirrel **(Funambulus pennantii)***

This small-sized semi-arboreal mammalian species is also known as five-striped squirrel with five dark longitudinal stripes along the back separated by dark brown. It is found all over the subcontinent, south of the Himalayas, and often lives around human habitations. Body length is around **7 i**nches and tail length **7** inches (**Fig. 4.17**) It is active and scrapes up and down the trees all the time. It is an attractive little rodent that looks a bit like a chipmunk and are very abundant in different riparian forests This animal show little fear of humans, frequently living around forest settlements and becoming fairly tame when encouraged. They forage on the ground and in the trees during daylight for seeds, nuts, young bark, buds, and other small food items and occur solitary or paired. They feed on a variety of food like fruits, vegetables, seeds, nuts, barks, and insects make roughly rounded nests in trees by aggregating leaves and small sticks. Their nests have an inner chamber with an entry in one side.

*4.14.3.5.1.1.4 The Three-Striped Palm Squirrel **(Funambulus palmarum)***

It has three stripes on its back and occurs commonly in the damp forests of western and eastern India and also in the peninsular India. They are very small in size (the maximum length is around **5** inches and tail length **6** inches). Their color is gray brown with pale color in the under parts. It has pale parallel lines running from head to tail on its back. They display diurnal activities and lead a semi-arboreal life. They are found in South India, Maharashtra, and Bihar.

4.14.3.5.1.1.5 The Dusky-Striped Squirrel (Funambulus sublineatus)

It has a speckled greenish-gray coat and four longitudinal stripes on its back. It is small and shy and is found in the dense forests of South India. Their total length is around **6** inches and tail length **7** inches. Their body furs are thicker and darker. Their three pale stripes are mostly restricted to the anterior part of their body and prefer to inhabit in riparian forests.

*4.14.3.5.1.1.6 Hoary-Bellied Squirrel **(Callosciurus pygerythrus)***

The Hoary-bellied squirrel, also named as Irrawaddy squirrel, has very restricted distribution only in some areas of northeastern India (Sikkim, Arunachal Pradesh, and northern part of West Bengal, India). This medium-sized (body length 10 inches with a tail of same length) and gray-colored squirrel is with rufous tinge at the upper parts of two limbs. They prefer to lead an arboreal life at the mid-canopy of moist deciduous forests near the riverine flows (**Fig. 4.17**).

*4.14.3.5.1.2 Indian Mole Rat **(Bandicota bengalensis)***

The body is covered with dark gray furs with blackish tinge. It has rounded face with broad muzzle and small ears with pink coloration. Its burrows have so many branches, with a dozen of burrow of openings. They are found to be in good numbers near the crop fields and human habitation within close vicinity of water bodies.

4.14.3.6 Porcupines (*Hystrix indica: the Largest Asiatic Rodent*)

Porcupines (Hystricidae) are the largest Asiatic rodent characterized by long quills. Adult animals may weigh up to **18 kg (Fig. 4.17).** Three species has a wide geographical distribution in the Middle East and also in the Indian subcontinent (Kashmir to Nepal and Sri Lanka). The most common is the crested porcupine, *Hystrix indica*. This animal is strictly nocturnal and lives in pairs but occasionally singly. Their burrows have a number of openings and the tunnels are very long. This animal is characterized by having body and tail covered with stiff quills of varying lengths interspersed with bristles which grow longer in the head and neck to form crest. That is why this species is referred to as the crested porcupine. This species also possesses tufts of short, hollow, open-ended quills attached to the skin. After being disturbed, this animal display aggressiveness by immediately erecting the quills on their back and stamped their feet on the ground. They are herbivores feeding on tree barks, roots, tubes, bulbs, and fruits. Porcupine is well protected due to its spiny armor and is well known to tackle larger carnivores. However, it is preyed upon by panther, hyena, and jackal.

4.14.3.7 Wild Animals Under the Order Lagomorpha

Lagomorpha lagomorphs – which literally mean "**hare-shaped**" – are found all around the globe. Classificatory scheme of the order Lagomorpha: **92** species in **13** genera and **3** families (**1** family, the Prolagidae, is extinct) – **(1)** family Leporidae (riverine rabbit (*Bunolagus monticularis*), hispid hare (*Caprolagus hispidus*), pygmy rabbit, (*Brachylagus idahoensis*)) with **62** species in **11** genera and (**2**) family Ochotonidae (alpine pika (*Ochotona alpina*), American pika (*O. princeps*), Moupin pika (*O. thibetana*)) with **30** species in the genus *Ochotona*. Besides, logomorphs are characterized by coats of long, soft fur that fully covers the feet, ears that are large relative to body size, and eyes positioned for good broad field vision. The family Ochotonidae includes single genus *Ochotona* (the pikas), under which a total of **30** species are present worldwide, whereas only **7** species are found in India. The family Leporidae (hares and rabbits) consists of **61** species under **11** genera, of which India has **4** species under **2** genera (Wilson and Reeder 2005). The species under the family Ochotonidae have small-sized body without a visible tail but possess short rounded ears and short forelimbs than hind ones, and the entire body is covered with grayish brown silky fur. The species under the family Leporidae are characterized by a medium-sized body (length from **50** cm to **75** cm), long hind limbs and feet, a small visible tail, and relatively long ears. The body of members of this family displays dark-colored dorsal coarse but wooly pelage (hispid hare) and light-colored ventral pelage. Pelage texture can be thick and soft or coarse and woolly (and may become increasingly sparse along the length of the ears). The pikas are thought to have separated from the rabbits and hares in the late Eocene around **38–35** million years ago. Rabbits and hares have elongated hind limbs adapted for running at speed over open ground. The ears are long, the nasal region is elongated, and their tail typically has conspicuous white underfur. By contrast, pikas are small with short legs and are well adapted for living in open meadow and steppe habitats, the tail is virtually absent, and the ears are short and rounded.

4.14.3.7.1 Diversity of Hares

There are three important varieties of Indian hares.

*4.14.3.7.1.1 Indian Hare **(Lepus nigricollis)***

The very attractive but timid mammalian species is characterized by upwardly directed long ears, laterally positioned eyes, and split upper lip (**Fig.** 4.17). Coat over the body is mainly rufous-brown in colors blended with black on the back. The tail is with rufous black color, whereas underparts are whitish. They are mainly nocturnal but also diurnal in undisturbed areas and occur solitary or in pairs. Their hind limbs remain folded, which enable leaping. They feed on grass, leaves, roots, tubers, fruits, and seeds. They prefer to breed during the winter season. Hares live in bush, jungle, and near cultivated lands on the outskirts of the villages. They are nocturnal and can be seen singly scampering across roads and fields at night. Grass and vegetable matter are their main diets. One or two youngs are produced during the colder months. Leopards, jackals, wild dogs, mongooses, owls, and crested hawks prey on them. Men hunt them for their meat and fur.

4.14.3.7.1.2 The Black-Naped Hare (Lepus nigricollis nigricollis)

It is a large, heavily built variety, with a dark, blackish brown patch on the back of its neck, up to the shoulder. The upper part of the tail is also black. It is found in most parts of the peninsula.

4.14.3.7.1.3 The Rufous-Tailed Hare (Lepus nigricollis ruficaudatus)

The body and tail are reddish-brown, whereas patches of gray furs are seen over the body. The face and back side are having black patches, whereas the under parts are white in color. This variety occurs from the south of the Himalayas to the Godavari River.

4.14.3.7.1.4 The Himalayan Mouse Hare (Ochotona roylei)

This small-sized hare looks like a guinea pig. It is small and has a round head, circular ears, short muzzle, and no tail. It is reddish-brown in color and has a band on the upper neck. It has a shining coat of short, straight hair. It lives in burrows. Being both timid and inquisitive, its behavior is interesting. It races across the ground playing hide and seek with any intruder. It is found right across the Himalayas in between **11,000** and **14,000** feet. It is commonly seen in rocky areas above the tree line, among the coarse grass, or under trees.

4.14.3.7.1.5 Hispid Hare (Caprolagus hispidus)

This brown-colored, large-sized (around **2** feet) endangered lagomorph is characterized by having small rounded and embedded ears under furs, comparatively shorter legs, and harshly coated body. The underparts of the body are white in color, whereas the color of the tail is brown throughout. This endangered hare species is now found only in the forest tracts and grasslands of northern parts of the State of West Bengal and Assam in India (**Fig.** 4.17).

4.14.3.8 Wildlife Under the Ungulates (Herbivores)

The ungulates contain the mammals which are most useful to man. This is a large and diverse group of animals developed from different evolutionary lines. Almost all the large herbivorous mammals are ungulates (cows, horses, sheep, elephants, camels, and other animals domesticated by human beings). The ungulates are not a single group and are classified together more for reasons of convenience than because all the animals are closely related. However, all ungulates have certain similarities, which are chiefly related to their method of feeding. Out of many even-toed ungulates of the subcontinent, the wild buffalo, gaur, deers, and pigs are most common in the forest tracts of the Gangetic Plain of eastern India.

4.14.3.8.1 Classificatory Scheme of Hoofed Mammals

Orders Perissodactyla and Artiodactyla contain **13** families, **88** genera, and **212** species. Odd-toed ungulates belonging to the order Perissodactyla includes (**1**) suborder Hippomorpha under the order Perissodactyla with family Equidae (equids), **9** species in **1** genera, represented mostly by African ass, domestic horse, and plains zebra and (**2**) suborder Ceratomorpha under order Perissodactyla with family Tapiridae (Tapirs), **4** species in **1** genus, and family Rhinocerotidae (rhinoceros), **5** species in 4 genera.

Even-toed ungulate order Artiodactyla includes:

1. Suborder Suina with family Suidae (wild pigs and boars); family Tayassuidae (peccaries), **2** species in **3** genera; and family Hippopotamidae (hippopotamuses), **2** species in **2** genera
2. Suborder Tylopoda with family Camelidae (camels and lamas), **6** species in **3** genera
3. Suborder Ruminantia with family Tragulidae (chevrotains), **4** species in **3** genera; family Moschidae (musk deer), **4** species in **1** genus; family cervidae (deer), **51** species in **20** genera; family Giraffidae (giraffes and okapi), **2** species in **2** genera; family Antilocapridae (pronghorn), only **1** species pronghorn (Antilocapra americana); and family Bovidae (cattle, antelope, sheep, and goats) **140** species in **47** genera

4.14.3.8.2 Characteristics and Interrelationships of the Ungulates

The term ungulates are applied to those groups of mammals that have substituted hooves for claws in their evolution, this feature having evolved independently within different ungulate groups. The evolution of hooves appears to follow from a commitment to a terrestrial herbivorous lifestyle; with rapid locomotion, most of the ungulates are exclusively herbivores; and they comprise around **80%** of species of terrestrial mammals that weigh more than **50 kg**. Living ungulates mainly belong to the orders Perissodactyla and Artiodactyla, which diverged from a common ancestor among the primitive "**condylarths**" some **65** million years ago. Despite the superficial similarities between horses and antelopes, rhinos and hippos, and tapirs and pigs, the former of each pair belongs to the Perissodactyla (odd-toed ungulates) and the latter to the Artiodactyla (even-toed ungulates). The similarities between them have largely come about due to the convergent evolution (natural selection favoring similar body plans in animals evolving from different ancestry). The relationship of the ungulates to the paenungulates (formerly known as subungulates) is now thought to be much more distant than previously assumed, as paenungulates are now included with the basal mammalian grouping of Afrotheria, which also includes aardvarks, tenrecs, and sengis. Super order Paenungulata (sometimes called subungulates) includes the huge elephant, the relatively small hyrax, and the aquatic dugongs and manatees which all look markedly different from one another. And yet, zoologists believe that these three orders of animals are more closely related to each other than they are to other mammals and so have grouped them together in the superorder Paenungulata (sometimes called subungulates).

All these mammals (with the exception of the sea cow) have an initial appearance and early diversification in Africa, and this may reflect the early isolation of a common ancestor on this continent. The three orders of paenungulates proper are (**1**) Hyracoidea (hyraxes), (**2**) Sirenia (sea cows), and (**3**) Proboscidea (trunked mammals, today represented only by the elephants) which share certain derived anatomical characters, including details of the structure of the skull, wrist, and placenta. Indeed, it has even emerged that the sea cows, which belong to the order Sirenia (dugong and manatees), may be more closely related to the elephants than are the hyraxes.

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4.14.3.8.3 Adaptive Strategies of Ungulates to Become Successful Wild Fauna

They often require special internal adaptations in order to digest their food. The four stomachs of the cow, for example, make it possible for it to digest cellulose, the main constituent of grass. The ungulates form a large group of ruminants, pure vegetarians with a complex arrangement of stomachs for digesting grasses and leaves. After being taken into the mouth, the food travels into one of the stomachs where it is partially digested and then regurgitated to the mouth to be chewed over again. The cellulose is normally indigestible for carnivores because they lack the necessary enzymes to break down the substances in their stomachs. Other vegetarian animals are well adapted for their escape from their predators. The gazelle, which is preyed upon by the big cats and dogs, has long legs and quick reflexes to run away from the attacks of predators. Other herbivores, like the elephant and the hippopotamus, are large and powerful enough to deter any meat-eater. The carnivores alive today are generally separated by zoologists into two main groups. One group contains cats and similar animals, the other the dogs, bears, weasels, and animals like them.

4.14.3.8.3.1 Deers: Common Wildlife of Forest Plains – Family Cervidae

In contrast to the large Bovidae that tend to dominate in riverine areas in the African tropics, especially in the savannah, dense forest along the rivers, and floodplains, less gregarious Artiodactyla in the families Cervidae, Tragulidae, and Moschidae are adapted to concealment in forests but make seasonal use of floodplains as a source of fresh grasses and forage. Different species of deer inhabitants of riparian forest also prefer to secondarily inhabit in tall-flooded grasslands and frequently visit shallow wetlands feeding upon aquatic plants. Their different eco-bio-ethological needs such as foraging, reproduction, migrations, and social behavior (congregation into herds) are linked with the annual river flood cycle.

Deer belongs to the family Cervidae of the order Artiodactyla of class Mammalia. These are herbivorous and form a significant component of grazing food chains of Indian forests, inhabiting a wide range of biomes that include swamp, tundra, deciduous forest, etc. tending to band together in compact herds. There is a fundamental difference between the antlers of deers and the horns carried by many other ruminants (Figs. 4.13 and 4.14).

Deers are very unique wild fauna of the ruminant families Cervidae, Moschidae, and Tragulidae, though, especially to the first of these. Of the nine deer species, the most familiar is the chital, commonly known as "**spotted deer**," which represents one of the beautiful deers found in considerable numbers in the riparian forest tracts and provides important sources of food for the carnivores. The four largest deers are the sambar, the barasingha, the thamin, and the hangul (the Kashmir stag). The hangul is a critically endangered deer species in India and is being protected in the moist temperate forest, especially in the Dachigam Wildlife Sanctuary in the northern part of Kashmir. The other ruminant families are the Bovidae (cattle, antelopes, sheep, and goats) and Giraffidae (giraffes of Africa). Unlike Bovidae, the animals grouped as deer do not have hollow horns; and they generally (not always in the Cervidae) have canine teeth in the upper jaw, in which Bovidae never have. Structurally the antlers of a deer are formed of solid bone, without a marrow cavity, sprouting directly from the pedicles on the frontal bone of the head but differ from the horns in two important ways: first, they are usually branched, and secondly, they are solid and are shed and regrown each year. The antlers of deers are not permanent structures; they undergo complete dropping and renewal each year unlike the horns of cattle, sheep, goats, and antelopes, which once broken off are lost forever. In deers, the shredding of the antlers causes a small hemorrhage which within a while get recovered by the development of a layer of cicatricial tissue depicting scars. The new antlers then start to sprout with a different look from the discarded pair, being enveloped in a downy sheath of velvet, and this skin layers are well furnished with blood capillaries carrying necessary growth elements and also supported by a network of sensitive nerve fibers. Besides, the ages of the animals are directly correlated with the development of the antlers along with the increase of branches or tines after being determined by diet and other ecological factors. There are four much smaller deer species: the muntjac, the hog deer, the musk deer, and the tiny chevrotain or mouse deer. The Tragulidae include the mouse deer or chevrotains, the smallest ruminants (the maximum height reaches to about little more than **1** foot) which have less complex stomach than other ruminants, large lateral hooves, big tusk, and wedge-shaped body. The Moschidae include only the musk deer which is characterized by having thick quilt fur which stands out from the skin; a tiny tail not visible externally, with a gland on it; very large lateral hooves; and a little (height is around **2** inches) antlers with two prongs. As compensation for lack of antlers, these deers pass long, curving upper canines or tusks that protrude downwards from the mouth. The muntjac or barking deer (*Muntiacus muntjak*) has both antlers and tusks. The antlers are exclusively male attributes, with the exception of the two species of the genus *Rangifer* – the reindeer (*Rangifer tarandus*) and the caribou (*Rangifer arcticus*) in which they are carried by both male and female alike. Owing to the limited shelter and food supply, deforestation, urbanization, mass hunting, etc., deer population has drastically come down.

4.14.3.8.3.1.1 Spotted Deer or Chital ***(Axis axis)***

They are **76–90** cm in height living in the herds of **20–30**. They are spotted with white or dark brown coat. It has long slender antlers which are shed annually. The antlers may attain a length of **1** meter but slender and may have extra twigs apart from the three main points. It is found all over the country except Assam, Punjab, and Rajasthan. They are seen in herd of **95–10** and prefer open-type forests with good grazing sites and running streams (**Fig. 4.13**).

4.14.3.8.3.1.2 Hog Deer ***(Axis porcinus)***

They are smaller but stout and hog-like in appearance. They live in solitary or in pairs and prefer to live in grass patches bordering the forests (**Fig. 4.14**). They are diurnal and come out to feed only during morning and evening. The hog deers, although they are related to chital in many respects, possess very small two-pointed antlers like the barking deer but with very small brow tines. Its habitat is dense grass along river banks and also in the plains where they suffer heavily the predation from leopard and other large cats.

4.14.3.8.3.1.3 The Barasingha or Swamp Deer ***(Rucervus duvaucelii)***

This swamp deer belonging to the family Cervidae differs from all other Indian deer species endowed with the antlers carrying more than three tines. This distinctiveness in the character of this deer species designates them as "**barasingha**," meaning "**12-horned**" and adult stags have been shown to possess **10–14** tines (Fig. 4.13).

They are paler in color than the sambar. Its antlers are readily distinguishable because they branch into numerous, upturned points and the brow tines are more curved stanza with bold on Barasingha. Barasingha: In natural forest habitats intermingling with grassy belts, the populations of deers (swamp deer or barasinghas) synchronize with the new growth of new tender green shoots for the deers to feed on. In the short mating season, each adult barasingha stag must quickly establish his dominance and win mates from the herds of hinds (females). Stags stand about **4 ft** high at the shoulder and have long manes. Their antlers are up to little less than **4 ft** long. The barasinghas feed on the tall grasses that border open, grassy areas amid slopes covered with rain forest. The animals forage in the early morning and evening, preferring to hide and ruminate in the long grass from midmorning to dusk, the hottest part of the day. Grazing domestic livestock has so seriously diminished the living space for barasinghas, and thus they are in the danger of extinction.

4.14.3.8.3.1.4 Thamin ***(Cervus elaphus)***

In the low scrub jungle of Southeast Asia lives the thamin or brow-antlered deer (*Cervus elaphus*). They resemble the barasingha except for its distinctively curved antlers, forming a forward-pointing semicircle from the brow tine to the tip, which has only three or four rather blunt points.

4.14.3.8.3.1.5 Barking Deer ***(Cervulus muntjac)***

They are **61** cm in height and have suborbital glands below their eyes. They have antlers and non-protruding canines and live in small families. They are diurnal and graze in the morning and evening hours. They have distinctive pedicles near the eyes (**Fig. 4.14**).

4.14.3.8.3.1.6 Musk Deer ***(Moschus leucogaster)***

It resides in the high altitude (**8000** meters) in the Himalayas in the coniferous forest belts in the mountain of Ladakh and Kashmir. This small animal is characterized by having very round bodies, elongated heads, and large ears but no antlers. Their so-called musk pods lie beneath the abdominal skin of the males.

4.14.3.8.3.1.7 Chevrotain or Mouse Deer ***(Moschiola indica)***

It is the smallest of deers. It has delicate very thin legs with four toes to each foot and a striped and spotted body. It does have any antlers but possess projecting canine teeth.

4.14.3.8.3.1.8 The Sambar ***(Rusa unicolor)***

Representing the India's largest deer, it is endowed with heavily maned stags carrying long, powerful antlers (little more than **2** feet in height) which divide into forks, with long curved brow tines. This deer feed mainly at night on grass, leaves, and fruits. They constitute the most attractive prey for the tigers which used to lure them by mimicking their calls. Besides, they form the preferred target of crocodiles too while they come to the waterbodies for drinking. Females of this deer bear single calve after around **9** months of gestation during pregnancy. Usually births of the cubs take place during late summer in India, and most males lead solitary stage during early monsoon with the velvet (hairy skin) on antlers. In India, mating takes place from September to April, after being influenced by the agroclimatic conditions of the region. The sambar stags roam widely but establish a small territory for the rut (display and mating). They roar loudly to attract six to eight hinds instead of rounding them up (**Fig. 4.13**).

*4.14.3.8.3.1.9 Himalayan Blue Sheep **(Pseudois nayaur)***

This is also called Helan shan, a caprid found in the high Himalayas of India. The size of this caprid is around **5** feet long along the head and body with a maximum height of **3** feet and with tail a little less than **1** foot. The body is coated with bluish gray-colored furs. The underparts are with bicolor combination with white and black combinations. The ridged horns are found in both the sexes, whereas in males, they grow upwards, then turn sideways, and curve backwards. The rutting of the bharal starts towards late November and continues mid-January. The young are born in late June or July (**Fig. 4.13**).

*4.14.3.8.3.2 Herbivorous **(Ruminants)** Large Wildlife Under the Family Bovidae (**Fig.** 4.15)*

The cloven-hoofed, ruminant mammals belonging to the family **Bovidae** (a member is designated as bovid) include bison, wild buffalo, water buffalo, antelopes, sheep, goats, and domestic cattle. Eight major subfamilies along with **143** species exhibit wide range of variations in respect of size and coloration. Except some domesticated forms, all male bovid have two or more horns and, in many species, structure of horns, dental formulae, etc. They demonstrate different modes of social (solitary and gregarious) and reproductive behaviors.

*4.14.3.8.3.2.1 Himalayan Brown Goral **(Nemorhaedus goral)***

This medium-sized (maximum length around **4** feet and maximum height of **2** feet) and brown-furred goat antelope with sluggish appearance prefers to inhabit in the scrub and grasslands in the mountain slopes of the northeastern Himalayas at an altitude between **1000** and **3000** meters, north of the River Brahmaputra. It possesses backwardly pointed ridged horns (**Fig.** 4.15).

*4.14.3.8.3.2.2 Wild Goat **(Capra hircus)***

This medium-sized (height around **3** feet) high-altitude goat is covered by hairs of variable colors which are season-specific. The chin of the male has beard. In contrast to the long curved horns of males, the females possess much smaller erect horns. This species is found in the ranges of the Himalayas, especially in the northeastern states of India (**Fig.** 4.15).

*4.14.3.8.3.2.3 Wild Yak **(Bos grunniens)***

The wild yak, a massive animal (maximum body length **10** feet and height **7** feet), is considered as a charismatic robust variety of domestic cattle which inhabits in the high altitude of the Himalayas, in the alpine forest range, and in the cold deserts of the State of Kashmir and also in the northeastern Himalayas (Sikkim).The body of this animal is coated with blackish brown fur. Their ears are strikingly small and muzzles are naked. It is often seen to bath in the icy rivers even during winter (**Fig. 4.15**).

4.14.3.8.3.2.4 Himalayan Tahr ***(Hemitragus jemlahicus)***

This high-altitude mountain goat is characterized by having robust body (**3** feet height) with prominent erected ears, backwardly curved horns, and light red-colored long hairs all over the body. The hairs on the neck and shoulder attain considerable length (around **6** inches) which anastomose to form shaggy mane extending to the level of the knee. This animal is distributed throughout the Himalayas ranging from Kashmir to northeast to Bhutan.

4.14.3.8.3.2.5 Takin ***(Budorcas taxicolor)***

Takin is a heavily built robust animal (more than **4** feet high and more than **6** feet long from the head to the tail). Their body is covered with multicolored furs (yellow to brown). This high-altitude bovid is distinguished by large head with thick curved horns, hairy muzzle, short tail, and strong legs. It lives in group or sometimes singly, preferably in the mountain forests with bamboo trees at an altitude of **3000** meters.

4.14.3.8.3.2.6 Gaur ***(Bos gaurus)****: The Largest Bovine in India*

In spite of having an impressive giant appearance (adult bulls weighing up to **1000** kg and standing **190** cm at the shoulder), the gaurs (*Bos gaurus*) are timid, forest-loving wild ungulates, usually moving in small family herds, and descend to the valleys from the hills to graze. Their body color is golden fawn, while cows and young bulls are dark coffee-brown with distinctive white stockings on their legs. They are mostly found in the forest tracts of central India and occasionally migrate down to the hilly forest tracts. This animal is often mistakenly called as the Indian Bison although it is not related to the North American bison. These world's most impressive oxen are endowed with short horns that arise from a hairy temporal boss and curve outwards and inwards and slightly backwards. Both sexes bear smooth cylindrical upsweeping horns, which are orange yellow in young animals becoming olive in older bulls. But this otherwise aggressive animals rarely attacks unless provoked. They are now with very scattered populations in the Western Ghats, in Madhya Pradesh and Odisha, and in the Himalayan foothill regions of Assam and Bhutan.

4.14.3.8.3.2.7 Wild Buffalo ***(Bubalus bubalis)***

This slaty black-colored wild counterpart of the domestic buffalo is distinguished by possessing very robust and strong body (maximum length of **10** feet and maximum height of **7** feet) and two curved but horizontally spread horns. The tail is long with a bushy tip and the horns curve upwards (**Fig. 4.15**). They live in herd in tropical deciduous forest mixed up with grassy belt in the close vicinity of rivers of the northeastern India (Assam, Arunachal Pradesh), in the river basins of Brahmaputra River and in forests of the states of Odisha, Madhya Pradesh, and Maharashtra. Previously, this animal was widely distributed throughout India, but their abundances are restricted to some reserve forests in the northeastern parts of India.

4.14.3.8.3.2.8 Wild Ass ***(Asinus hemionus)***

Only one species of horse family is found in the Indian subcontinent that is wild ass. They are found mostly in saline clay desert of the Little Rann of Kutch, sharing the habitats with chinkara gazelles and nilgai. Their number was greatly reduced due to hunting, capturing for breeding mules, surra disease, and African horse sickness disease. Being the only true "**wild ass**," it needs protection and conservation **(Fig. 4.15).**

4.14.3.9 Antelopes: An Important Contributor in the Wild Faunal Diversity in India

There are four species of antelopes found in India. These are Indian gazelle, nilgai, blackbuck, and chowsingha. All these species belong to other subdivision of the family Bovidae [(family Pantholopinae (blackbuck and chowsingha) and family Antilopinae (antelopes and gazelles)] demonstrating characteristics different from sheep or goats alongside sharing some of the common characteristics.

4.14.3.9.1 The Chinkara or Indian Gazelle ***(Gazella bennettii)***

Gazelle live in herd migrating together from one place to another covering a stretch of even **15** km without even water, but in dry conditions, they drink each morning and evening. The gazelles graze the short grass and tender leaves of forest vegetation. The adults of this ungulate deers are preferred by leopard, wild dogs, lions, and hyenas as their preys. It attains a maximum height of a little more than **2** feet and gains a maximum weight around **25 kg**. The dorsal part of the gazelle is coated with pale reddish colored fur, while the furs in the throat and belly are white in color. The sides of the face are marked by deep chestnut stripes from the corner of the eye to the muzzle. Males establish territories up to **300** meters which are used mostly by the reproductive activities. Females give birth to only single fawn which is born from a pregnant female after a gestation period of **6** months, and during that phase, females find a suitable place maintain a solitary life (**Fig. 4.13**).

4.14.3.9.2 Nilgai *(Boselaphus tragocamelus)*

This Indian's largest antelope lives in herds of **4–10** animals. It is **130–140** cm in height and lives near cultivated lands (**Fig. 4.13**). Young bulls and cows are tawny, but old males have iron gray color. Both the sexes have two white spots on each cheek and a white gular patch on the tails and belly. The males have long wispy beard and short conical black horns. It is regarded as a sacred cow but is hunted for the protection of crops (**Fig. 4.13**).

4.14.3.9.3 Blackbuck *(Antilope cervicapra)*

This exclusive antelope of Indian subcontinent is characterized by having broad eye ring, proportionately long tightly coiled horns. This fast running animal is found in grassy plains of India. The males are dark brown or black in color, whereas females have tanned fur with white bellies. Blackbuck is a polygamous and gregarious animal (**Fig. 4.14**).

4.14.3.9.4 Four-Horned Antelope or Chausingha *(Tetracerus quadricornis)*

This is small light-browned antelope. Males of two subspecies of this antelope have two pairs of horns, where the front pair is shorter. The color of the body is pale red-brown on the dorsal side while creamy white in the ventral side. A pair of well-developed glands is present between the false hooves of the hind legs in both males and females. They lead a solitary life and is found in the forest near the water bodies, on which they depend very much.

4.14.3.10 Rhinoceros (*Rhinoceros unicornis*, Order Perissodactyla): A Wild Charismatic Herbivore with Restricted Distribution

The second largest animal of the Indian subcontinent is the Indian one-horned rhinoceros formerly distributed throughout the Gangetic Plain and even in the middle reaches of the Indus in Pakistan; it is now restricted to a very few areas such as the Kaziranga National Park and Manas Reserve in Assam, Jaldapara Reserve in North Bengal, and Royal Chitwan National Park in Nepal.

The second largest animal of the subcontinent is the Indian one-horned rhinoceros. Of the world's five species, only the African white rhinoceros exceed it in weight. Its single stubby horn is rarely longer than **38 cm**, the majority being much shorter. It has a single horn on the nose. The horn is made of keratinized skin and matted hair. Formerly distributed throughout the Gangetic Plain and even in the middle reaches of the Indus in Pakistan (where a pair from Nepal has recently been reintroduced in the Lal Suhanra Reserve), it is now restricted to a very few areas, such as the Kaziranga National Park and Manas Reserve in Assam, the Jaldapara

Reserve in North Bengal, and the Royal Chitwan National Park in Nepal. The total number surviving is about **1200** in India and **300** in Nepal, and they are breeding successfully under protection. Like the African and other Asian species, the one-horned rhinoceros have suffered persistent persecution for the supposed medicinal, and to a lesser extent the aphrodisiac, value (**Fig. 4.16).**

4.14.3.11 Tapir (*Tapirus indicus*)

The tapir is large mammal that despite its pig-like appearance, characterized by having a prolonged trunks, is believed to be most closely related to hippopotamus and rhinoceros. They are found in moist dense forests of southern hemisphere. Tapirs and rhinos are close relatives with the perissodactyl clad, Ceratomorpha. Early members of both the lineages look similar (**Fig. 4.16**).

4.14.3.12 Hippopotamus (*Hippopotamus amphibius*)

This huge-sized mammalian fauna belonging to the order Artiodactyla and family Hippopotamidae, also known as "**river horse**," is an inhabitant of river ecosystem. This is a semiaquatic omnivorous ungulate mammal (the fourth largest mammal after blue whale, elephant, rhinoceros) and distributed to the African subcontinents. Adults may achieve a biomass of **2** quintals (**Fig. 4.16**). Despite their physical resemblance to pigs and tapir, the closest living relatives of this species are the cetaceans (whales, dolphins, and porpoises).

4.14.3.13 Elephants (*Elephas maximus*): Under the Order Proboscidea

The Indian elephant is the largest terrestrial mammal and is confined to the Tarai areas. It is gregarious, and its herds move constantly in search of new feeding grounds. The elephant of Asia and India, known by the scientific name *Elephas maximus*, is the second largest land mammal living on earth today (**Fig. 4.12**). The Indian elephant representing another charismatic large mammals of the world is characterized by having smaller ears, rounded back, four nails in the hind feet, and only one lip in the trunk. Being forest animals, they have suffered, like so many others, from the relentless erosion of their habitat. Only its relative, the African elephant (*Loxodonta Africana*), is bigger. These two species are the sole survivors of a once rich and varied group, and both are now threatened with extinction. Most people are familiar with the general outward appearance of an elephant, but may not know how to distinguish the two surviving species. The African is the larger of the two, a big bull standing **3.35 m** (**11 ft)** or more at the shoulder and carrying tusks about **2.13 m** (**7 ft**) long. The Asian species seldom stands more than **3.05 m** (**10 ft**) at the shoulder, and its tusks average about **1.37 m** (**4.5 ft**) in length, with the longest known pair measuring **2.59 m (8.5 ft**). Whereas the female of the African species carries quite long tusks, the Asian female either is tuskless or has very small tusks, known as "**tushes**," which often do not project beyond the jaw. Many Asian males are tuskless and are known as "**mucknas**." The back of the African elephant shows a marked dip between the fore and hind quarters, whereas that of the Asian forms an unbroken convex curve. The African has a comparatively elongated face with a flat forehead; the Asian has a more rounded face, with a twin-domed forehead. The ears are most distinctive, being so large in the African species that they cover the whole of the neck and shoulders and reach as low as the breast; the ears of the Asian species are comparatively small. The African's trunk is marked by repeated horizontal ridges and ends in two fleshy processes or "**fingers**"; the Asian's trunk is smooth and has only one such finger.

The elephant is entirely vegetarian and subsists on a wide variety of woody plants, palms, bamboos, and other grasses. An adult requires about **270 kg** (**600 lb**) of such food daily. This is gathered and prepared for ingestion by the combined use of the trunk, tusks, and feet. Elephants also drink by drawing water into their trunks, up to **9** liters (**2** gallons) at a time, and then releasing it into their mouths. Large elephants have been known to drink **227 liters** (**50** gallons) of water in **1** day.

4.14.3.13.1 **Breeding Behavior**

Although uncertain, the breeding season of Asian elephants in different parts of this country is believed to be during summer till the commencement of rainy season. Females reach sexual maturity between **9 and 15** years of age, while males reach sexual maturity at **15** years. Male elephants (rarely females) sh4ow peculiar periodical signs of excitement on attaining sexual maturity, mostly during the cold season, which is known as "**musth**," when an elephant exhibits some erratic behavior especially for having a partner of opposite sex. After mating, the pregnant elephant carries the fetus for nearly **2** years before giving birth usually one offspring, which is one of the longest gestation periods for any mammals. After the birth of an offspring, the female members of the herd take care for nurturing both the mother and her baby. The groups consist of adult females with their immature calves of both sexes. Because of their slow growth rate, there is a long period of attachment between mother and calf, and it is not unusual to see one or more calves of different ages and sizes at heel behind their mothers at the same time. As they mature, the bond of attachment weakens and calves stray father from their mothers.

There are other unique features to elephant dentition apart from their tusks. Each jaw carries two molars, each of which is replaced six times during the animal's life by a progressively more massive and complex tooth. As the food they eat is coarse, elephants' teeth are worn away quite fast, and the replacements are therefore essential. However, when the sixth and last set has been worn down, elephants cannot eat properly and will eventually die. Usually, however, an elephant will die from other causes before reaching this stage.

The Asian elephant's only serious enemy is man, thanks to his greed for ivory and space. Man's development of elephant habitat is the biggest threat to the species in Asia. Throughout India, the elephant and the man live in constant conflict with each other; the elephant regularly raiding the cultivated crops of man and killing several human beings every year and the cultivator harassing and killing an equal number of elephants.

Indians have captured and domesticated elephants for at least the last **3000** years; a large number are still captured and used for hauling timber, for riding, and as a prestige symbol for temples. A large community of artisans and traders (estimated to be **7200** in **1980**) depends on ivory for their livelihood, and a number of tuskers are regularly poached for this purpose. Man is also continually encroaching into the remaining habitat of elephants which is ever shrinking and fragmenting. There is clearly a real threat to the continued existence of the Asian elephant in India.

4.14.3.13.2 Home Range and Social Organization

Asian elephants have a larger home range as compared to other terrestrial mammals and practice seasonal migration. They usually roam over large areas ranging of more than **600 km** ^{2}. Asian elephants lead a very social styles obeying and following a wide range of complex community laws, rules and regulations, and many well-established social customs as part of their gregarious mode of life patterns.

4.14.3.13.3 Behavioral Ecology of Elephants

Asian elephants are terrestrial animals and generally lead a diurnal mode of life spending the hot summer days within denser forests and coming out from the forests to invade into open stretches especially with cultivated lands. They migrate over long distances in pursuit of food and water and in search of security usually following known pathways, designated as "**corridor**." Destruction or blocking of these "**corridor**" by human activities has compelled them to make an inroad into the human settlements, which often lead to human–elephant conflict. They love to bathe and shower themselves with water and afterwards with dusts to repel insects.

4.14.3.13.4 Foraging Behavior

Asian elephants being strictly herbivorous animals prefer to have various kinds of grasses, leaves, and barks of specific kinds of trees from the natural forest tracts, spending a considerable periods (more than two-thirds (**14–19 hr**) of the day) in persuasion of feeding depending upon the habitat and season. They defecate about **16–18** times a day, producing about **100 kg** of dung/adult elephant. During the dry seasons, the larger herds often break up into smaller groups to explore different habitats and again reunite once the condition is favorable. The herd generally follows a regular and synchronized routine of drinking and feeding at specific places.

4.14.3.14 Indian Pangolins (*Manis crassicaudata*): A Unique Armored Plated Edentia

Formerly classed in the order Edentata, meaning without teeth, along with the sloths, they are now grouped under Pholidota (scaled animals). The dorsal and lateral sides of a pangolin and the outside of its limbs are covered with large overlapping scales composed of modified agglutinated hairs. Coarse bristle like hairs occur on the undersurface of the body and few grown between the scales. Pangolins are nocturnal in habit, spending the day in their burrows which are long tunnels ending into large chamber. The foods constitute various kinds of ants and termites. Probably stronger carnivores can prey upon them as pangolins roll into a ball for defense and exhibit enormous muscular power that defies any ordinary attempt to unroll them.

The armored-plated Indian pangolin, also called the scaly ant-eater, tail are protected by strong and overlapping scales. When frightened, it instantly curls up into a tight ball. The Pangolin feeds on termites and ants and has a dignified, ambling gait, walking with long, curved claws of its forefeet turned inwards to support its weight (**Fig. 4.17**).

4.14.3.15 Order Chiroptera: The Flying Mammal

Chiroptera is the largest order under the class Mammalia having **7** families and **50** species followed by the order Rodentia (**31** species in **3** families), Carnivora (**25** species in **7** families), Artiodactyla (**11** species in **4** families), Insectivora (**9** species in **2** families), Primates (**5** species in **2** families), Lagomorpha (**1** species in **1 f**amily), and Scandentia, Proboscidea, Pholidota, and Lagomorpha with one species each in one family. Bats (flying foxes) are the only mammals that truly fly. They have modified forelimbs and greatly elongated fingers that form a framework for a continuous membrane which is attached to the side of the body. Flying fox (*Pteropus* sp.) also known as fruit bats belongs to the order Chiroptera under the class Mammalia, the body length of which varies from **7** inch to **17** inch and body weights also range from **45** gm to **1,5** kg. The distance between the tips of the two wings in fully expanded state ranges from **23** inches to **66** inches. The genus *Pteropus* includes **59** species which are characterized by having muzzle resembling of a fox.

Bats, our only flying mammals, play a most valuable role in the rural area. An average insectivorous bat eats a round 1 kg of insects per week. They are being badly affected by insecticides and pesticides. Our artificial attempts to check pests might, therefore, prove to be self-defeating. Fruit-eating bats propagate plant life by carrying fruit to far off roosts and dispersing the seeds on the way. So great is the quantity of seeds so carried that in parts of Bengal the ground under which large colonies of flying foxes habitually roosted was rented annually for the right of seed collection. It is reported that in the Sahara Desert, flying foxes have created a grove of our neem tree by seed dispersal. Finally, fruit bats also enjoy eating flowers and so are responsible for cross-pollination. Flying foxes are most frequently found in the riparian and coastal forest areas spending most of their nonforaging time hanging upside down, roosting in typical bat fashion within trees. Indian bats (*Myotis sodalis*) are the medium-sized member of the genus *Myotis* (length **2–4** inches, weight **7** gm). They are pinkish white in color with small hind feet (**Fig. 4.17**).

4.14.3.16 Aquatic Mammals

Yet over two-thirds of the surface of the planet is covered with water, so it is hardly surprising that in the course of evolutionary time some of them should have taken advantage of the expensive aqueous niche. Whales and dolphins have subsequently adapted to the physical properties of water and evolved in ways that would not have been possible had they remained on land; only supported by water's dense buoyancy could be largest whales have reached their present size. Whales are the largest group of aquatic mammals and the best adapted to life in water. They are able to withstand major pressure changes involved in deep diving and are insulated against the cold by a thick layer of fatty blubber. They are also streamlined for the fast and efficient movement. Whales having a streamlined body differ from the fish by possessing specified mammalian features such as warm-blooded, breathing air through the lungs, and giving birth to living young that suckled on milk secreted by the mammary glands of the mother. Of the three marine mammal orders: Pinnipedia (seals, sea-lions, and walruses), Sirenia (dugongs and manatees), and Cetacea (to which whales and dolphins belong), it is Cetacea that are most specialized to water; pinnipeds must return to land or ice to breed. One-half of the order Cetacea comprises generally of dolphins and porpoises. They belong to the suborder Odontoceti, or toothed whales, which in total accounts for **72** of the **85** cetacean species.

4.14.3.16.1 Classificatory Scheme for Aquatic Mammals

Order Cetacea: **14** families, **40** genera, and **86** species
Suborder Odontoceti (toothed whales):

River dolphin family Lipotidae, Iniidae, Platanistidae, and Pontoponiidae, **4** species in **4** genera in **4** families: Yangtze River dolphin (*Lipotes vexillifer*), Amazon dolphin (*Inia geoffrensis*), Ganges dolphin (*Platanista gangetica*), and franciscana dolphin (*Pontoporia blainvillei).*

Dolphin family Delphinidae: At least **36** species in **17** genera including pantropical spotted dolphin (*Stenella attenuata*), common dolphin (*Delphinus delphis*), killer whale (*Orcinus orca*), pilot whale (*Globicephala melas*), etc.

Porpoise family Phocoenidae: **6** species in **3** genera including harbor porpoise (*Phocoena phocoena*) and finless porpoise (Neophocaena phocaenoides)
Beluga and narwhal family Monodontidae: **2** species in **2** genera including beluga (*Delphinapterus leucas*) and narwhal (*Monodon monoceros*)
Sperm whale family Physeteridae: **1** species in **1** genus including pygmy sperm whale (*Kogia breviceps*) and dwarf sperm whale (*K. simus*)
Beaked whale Family Ziphiidae: At least **21** species in **6** genera including northern bottlenose whale (*Hyperoodon ampullatus*), Blainville's beaked whale (*Mesoplodon densirostris*), and Cuvier's beaked whale (*Ziphius cavirostris*)

Baleen whale suborder Mysticeti:

Gray whale family Eschrichtiidae: **1** species, *Eschrichtius robustus*
Rorqual family Balaenopteridae: **9** species in **2** genera including blue whale (*Balaenoptera musculus*), fin whale (*Balaenoptera physalus*), minke whale (*Balaenoptera acutorostrata*), and humpback whale (*Megaptera novaeangliae*)
Pigmy right whale family Neobalaenidae: **1** species (*Caperea marginata*)
Right whale family Balaenidae: **3** species in **3** genera including bowhead whale (*Balaena mysticetus*) and northern right whale (*Balaena glacialis*)

4.14.3.16.2 **Dolphins of the Order Cetacean: One Flagship Species of Freshwater Rivers**

Two very unique interrelated aquatic species deserve the attention of wildlife ecologists, the Gangetic and Indus dolphins which belong to the order Cetacean. Five species of dolphins and the little Indian porpoise are seen in the river estuaries or offshore water of the oriental zoogeographic realm. Out of five different species in the Indian subcontinents, the **Gangetic dolphin, Irrabati dolphin, and Indus dolphin** have been the subject of research as flagship species and are now listed as endangered species. The two Indian dolphins mainly lead solitary life patterns not as gregarious species. They are characterized by having rudimentary eyes and feed on smaller aquatic fauna such as zooplankton and benthos. Not being gregarious, they have rudimentary eyes and feed on zooplanktons and other small crustacean on the river beds, mostly restricting their movements in the fresh to semi-saline riverine tracts. As per as volant mammals in the riparian tracts are concerned, out of the long list of Indian bats, the fox bats need special mention because of their nocturnal gregarious behavior, as pollinators of fruit-bearing jungle trees.

4.14.3.16.2.1 Gangetic Dolphin ***(Platanista gangetica)***

Slaty dull black-colored freshwater dolphin (maximum length is around **7** feet), belonging to the family Platanistidae, is characterized by stocky body, elongated beak endowed with sharp and interlocking teeth, rounded middle part of the body, bit elevated hump-like neck, and paddle-shaped flippers. They mostly move in the water in a group of five members and emerge from the surface of the water to breathe. It hunts fish and other aquatic fauna by their ability of ecolocation (**Fig. 4.17**).

*4.14.3.16.2.2 Irrawaddy Dolphin **(Orcaella brevirostris)***

This dolphin belonging to the family Monodontidae attains a maximum length of **8** feet and is characterized by blunt head without beak, gray-bluish body color with creamy white underparts, presence of crease on the neck, triangular bur small dorsal fin, and broad flattened flippers. They catch the prey by ecolocating the targets (**Fig.** 4.17).

*4.14.3.16.2.3 Finless Porpoises **(Neophocaena phocaenoides)***

This represents smallest Cetacea of the world (maximum size around **5 feet**) and representative of porpoise. Its blunt snout is continuous with the cylindrical main body. It is devoid of any fins but flippers are long and tapering. The tail is distinctly notched and teeth are spade-shaped. This is found in the confluence of estuary with sea (Odisha, West Bengal,) having sandy texture of the bottom soil (**Fig. 4.17**).

4.14.4 Amphibia: Characteristics and Classification

The Amphibia represents that group of animals which bridges the gap between dry land and water and occupy a place somewhere in between the fish and the reptiles in the evolutionary scheme of animal kingdom. The class Amphibia includes three orders such as Anura, Urodela, and Caecilians. The latter are much less well known, being worm-like burrowing animals, almost entirely blind, and completely limbless. Amphibians, especially anurans, contribute immensely towards ecological and economic benefits of the human beings by acting as biocontrol agents for controlling harmful insects, offering themselves as food for so many commercially and ecologically important aquatic and terrestrial fauna, etc. However, the diversity and density of Amphibia are in the process of sharp decline due to the habitat destruction, accumulation of persistent agricultural wastes, and bacterial and viral attacks due to the deteriorating ecological health of the ecosystems,

The class Amphibia is unique by practicing double modes of life both in water and land and is characterized by having moist glandular skins without any scales, soft toes without any claws, a two chambered heart in the larval stage and three chambered in the adult stage, external fertilization of eggs, and experiencing the process of metamorphosis. The class is represented by three orders: Apoda (e.g., worm-like caecilians, Caudata (tailed Amphibia, e.g., newts and salamanders, and Salientia which includes frogs and toads.

Among the living types of amphibians, out of **1800** amphibian species across the world displaying a wide range of variation in respect of colors and adaptive behaviors (digger, swimmer, climbers, etc.), the most successful is undoubtedly the frogs and toads, the anuran representatives, which are endowed with sense organs for sight and smell. They have a short squat body without any tail and possess long powerful hind legs in contrast to the fore legs. The males emit sound (the hoarse croaking of the bullfrog) to call the females especially during the breeding season from the breeding areas, different water bodies such as the ponds, streams, and rivers. These calls being the species-specific enable the females to locate the male partners of the same species.

Both toads and frogs are widely distributed all over the world and are thought to have distributed by the natural processes like storms, rainfall, etc. A major difference between the largest order Anuran (frogs) and the second large ones under the class of Amphibia is the urodeles (salamanders and newts, mud puppy, etc.), which retain their tails in adult life and also possess external gills as breathing structures. Its legs are small and not effective in the water. In addition, they often have a crest of the skin along the upper and lower edges of the tail which are useful aids in swimming. The third order, under the class Amphibia, the Caecilians are with soft tubular body without any limbs, having a compact head protected by a bony shield, mainly live within the moist soils by adopting fossorial mode of adaptation.

Some major species of Amphibia are encountered in tropical climatic environment of India (Dutta 1992; Pratiher and Deulti, 2012).

4.14.4.1 Common Asian Toad (*Duttaphrynus melanostictus*)

This relatively large-sized toad is characterized by having distinct head on which and other parts of the body a number of black warts are present. Besides, the head also possesses cranial ridges and parotid glands. The tympanum is round in shape and toes are not fully webbed. The major part of the body is brown to gray in colors, whereas the ventral part is creamy white. This common Asian toad is nocturnal in habit, and males emit sound from a single vocal sac during breeding season. They occur both in the southern and eastern India. They are also common throughout the plains of India and also in Nepal, Sri Lanka, Myanmar, South China, and Malay Peninsula (**Fig. 4.19**).

4.14.4.2 Ferguson's Toad (*Duttaphrynus scaber*)

The head of this very common toad bears distinct ridges and provided with warts and flat tubercles. They have round but indistinct parotid glands. Their tympanums are round and toes are not webbed. Their bodies are olive brown in color with yellowish white color in the underparts. This nocturnal toad prefer to inhabit in the water logged bushy areas and also by the side of paddy fields. They dig burrows beneath soils or utilize the holes of rotten woods to take shelter during nonbreeding season. They feed mostly the insects but also predate on snails and other aquatic invertebrates. They are found throughout the length and breadth of India.

4.14.4.3 Indian Skipper Frog (*Euphlyctis cyanophlyctis*)

Their body is flat and oblong with indistinct head having pointed snout. Two prominent round eyes are located dorsally. Their feet are webbed. Their yellowish-colored skin having rounded granules are present on the dorsal side, while the color of the ventral parts are creamy white. They remain active both at day and night, swimming in the shallow water, and predate aquatic insects and small fishes. They also breed throughout the year. They are found throughout India in freshwater habitats (**Fig. 4.19**).

4.14.4.4 Puddle Frog (*Occidozyga lima*)

This small-sized (around **2** inches) nocturnal and brown-colored frog having some dark spots over the body and pale yellowish mid-dorsal band breeds during late summer and early monsoon and feels comfortable in shallow water bodies. The snout of the head is triangular and toes are webbed. They feed mainly on insects (**Fig. 4.19**).

4.14.4.5 Indian Bull Frog (*Hoplobatrachus tigerinus*)

This frog is having an elongated body attaining a maximum length of about **5** inches. They display grayish green to yellowish in colors during different phases in their life cycles. Their head is bit conical in shape with pointed snout. A number of longitudinal folds are present on the dorsal surface of their body. Their long muscular legs are partially tuberculated. This frog is being captured in great numbers in many areas. This nocturnal species inhabits in the bushes along the edges of water bodies, and males emit combined sound during the breeding season.

Owing to the intensive collection of this species, they are no longer seen in many places where it was plentiful a few years ago. Besides, these frogs can become important biocontrol agents as they eat mosquito larvae. They are distributed throughout the monsoon-fed areas of India (**Fig. 4.19**).

4.14.4.6 Jerdon's Bull Frog (*Hoplobatrachus crassus*)

This strong-bodied and olive-colored frog is distinguished by pointed snout, webbed toes on comparatively short but stout legs, and presence of longitudinal ridges (around **10**) on the smooth dorsal skin, and several warts occur on the side of their body. They lead a semiaquatic life in the lowland areas and are encountered both in the day and night. They mostly live on insects and worms (**Fig. 4.19**).

4.14.4.7 Cricket Frog (*Minervarya orissaensis*)

This medium-sized amphibian species (little less than **4** inches) share both aquatic and terrestrial conditions by virtue of their adaptability. They are characterized by the triangular protruded snout, presence of longitudinal glandular but interrupted folds, and a strong fold from the back of the eye to above the shoulder. They also possess smooth venter, long hind limbs with rounded tips **(Fig. 4.19**). They prefer to inhabit in moist terrestrial environment nearer to freshwater wetlands in the crevices or burrows but sometimes are found to intrude the brackish water zones.

4.14.4.8 Tree Frog (*Chirixalus simus*)

This small-sized tree frog (maximum of **2** inches) commonly known as "**Assam Asian frog**" has also been recorded from the riparian forests of the states of West Bengal and Odisha, India. During the breeding time, they form foam nests hanging from the plants over the water (**Fig. 4.19).**

4.14.4.9 Tree Frog (*Polypedates maculatus*)

This unique tree frog inhabiting **in** tropical moist deciduous forests, grasslands, flood plains, and swampy areas close to human settlements is characterized by having elongated body with mosaic of colors as revealed during different phases of life cycle (light-brown to olive brown to reddish brown), bony head, and presence of dark streak passing through the eyes to almost middle part of the body, and the back side of their hind legs is ornamented with yellow spots bordered by black color (**Fig. 4.19**). This true arboreal species is often encountered on walls of human houses and preys mostly on insects and hidden under rocks. Males have been reported calling from the ground. It breeds in shallow water bodies during monsoon.

4.14.5 Reptiles and Their Diversity and Roles in the Riverine Ecosystem (Figs. 4.20, 4.21, 4.22, and 4.23)

4.14.5.1 Reptiles and Their Evolutionary Background

All life began in the oceans of the earth, but later some animals moved from the waters to the land in order to exploit the way of life which was offered there. The very existence of reptiles on earth have been for nearly **300** million years, but they have assumed some importance as an integral part of the earth's biodiversity, around a century back because of their functional roles towards the sustenance of both aquatic and terrestrial ecosystems. Research interests in the herpetological science have originated not only for the sake of research but also in view of increasing public

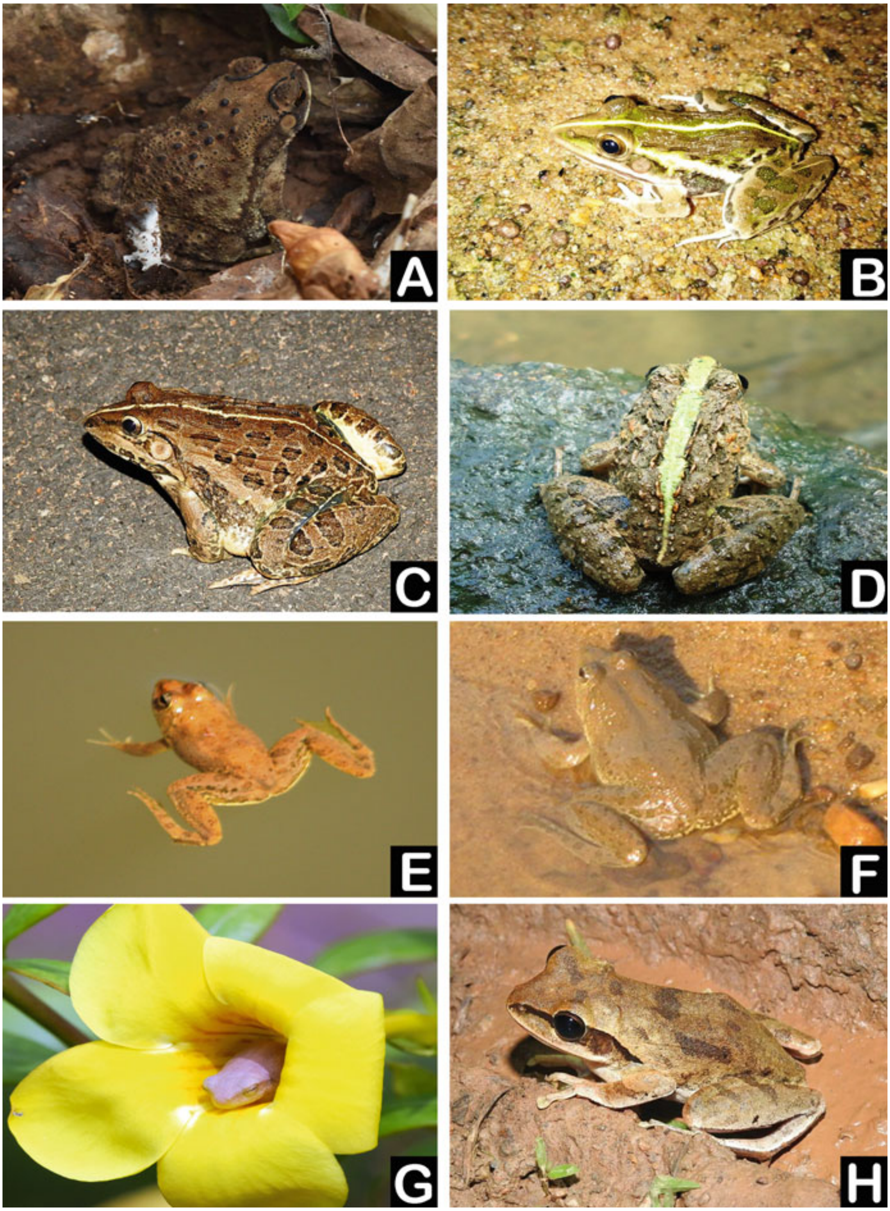

Fig. 4.19 Some interesting species under the class Amphibia of Indian subcontinent
(**A**) Common Asian toad (*Duttaphrynus melanostictus*)
(**B**) Indian bull frog (*Hoplobatrachus tigerinus*)
(**C**) Jerdon's bull frog (*Hoplobatrachus crassus*)
(**D**) Cricket frog (*Minervarya orissaensis*)
(**E**) Puddle frog (*Occidozyga lima*)
(**F**) Indian skipper frog (*Euphlyctis cyanophlyctis*)
(**G**) Tree frog (*Chirixalus simus*)
(**H**) Tree frog (*Polypedates maculatus*)

interests and awareness towards the conservation of reptiles. Reptiles are mainly represented by three major groups: the turtles, the lizards and snakes, and the crocodiles. A true reptile being a vertebrate animal is characterized by having body scales of epidermal origin, ability in laying of eggs, and dependence on outside sources for the maintenance of body temperature.

4.14.5.2 Broad Classificatory Scheme with Characteristics of Reptiles

Reptiles representing the first terrestrial but cold-blooded vertebrates are characterized by having skin covered by horny scales and respiratory organs for aerial respiration. Modern Reptilia are represented by four different orders. The three most common are the Squamata (lizards and snakes), the Crocodilia (crocodiles, caimans, and alligators), and the Chelonia (turtles and tortoises). The fourth order is the Rhynchocephalia, and this has one surviving species, the tuatara, which is found only on small islands of the North Island of New Zealand.

The typical lizard has an elongated body with two pairs of limbs terminating in **5**-toed feet. The difference between lizards and snakes lies firstly in the distribution of scales. The snake has transverse scales across its belly, while in the lizard, the entire body remains covered with small horny scales. Secondly, the formation of the jaw differs in between these two groups. A snake unlike lizard is able to swallow meals much bigger in diameter than itself. This is because the jaws are cunningly articulated, the lower one being split into halves connected by rubbery tissue. The teeth of the snake are thin, pointed and tip backwards towards the throat.

The order of lizard is itself divided into several families with several interesting genus and species such as water monitors, chameleons, geckoes, etc. The snake, belonging to the suborder Squamata, is a fascinating limbless creature for which man seems to feel an innate repulsion, but only about **250** species out of a total of some **2400** species of snakes across the world are in fact poisonous to man. In the poisonous varieties, the venom sac is situated in the upper jaw, and the associated teeth have either grooves running down the outside or a canal running through them to carry the poison to the bitten victim (Daniel 2002; Dutta et al. 2009).

4.14.5.3 Major Faunal Groups Under the Class Reptilia

4.14.5.3.1 Snakes (Fig. 4.23)

A total of **300** (approximate) species of snakes have been recorded from India which display a lot of diversity in respect of their shapes, length, color, etc. The larger snakes play a significant role as controllers of rodents. One large rat snake eats six to seven rats each week, and the big snakes such as cobra, **Russell's viper**, sand boa, and several others are mainly rodent-eaters. They are effective in a way that pesticides cannot do as they can burrow and bill a rat right in its hole. Rural India is still with the beliefs that lead to damaging effects on the continued existence of snakes**.** There is a need, therefore, to check over booming skin trade which is responsible for a colossal destruction of these reptiles.

4.14.5.3.1.1 ***Indian Rock Python (Python molurus molurus)***

They are very long and bulky snake with brownish dorsal side with black patches and creamy underparts. This gigantic snake (maximum length around **20** feet) is characterized by lance-shaped head and short, prehensile, and tapering tail, rudimentary hind legs, scaly snout tip, and a vestigial claw (spur) on each side of the anal scale. They prefer to inhabit in moist and shady places and mostly lead solitary and nocturnal life. They feed on small mammals and birds by capturing and killing the prey by twisting and constricting. They occur throughout the length and breadth of India (**Fig. 4.23**).

4.14.5.3.1.2 Spectacled Cobra ***(Naja naja)***

This is one of the deadly poisonous snakes (maximum length round **7** feet), which enjoys wide range of distribution all over India, and is characterized by dark brown colors with yellowish cross bands and creamy underparts, distinct head, large black eyes and large nostrils, the presence of spectacled-like marking which is only visible when the hood is spread, and two eye-shaped black marks connected by a U-shaped line. After being disturbed, it can raise its body off the ground. Inhabiting in the forests, grasslands, paddy fields, and other old derelict places with moist and humid conditions, this snake predates rats, birds, frogs, etc. (**Fig. 4.23**).

4.14.5.3.1.3 Jaldhara ***(Xenochrophis piscator)***

Jaldhara is a long (maximum length is around **5** feet), cylindrical nonpoisonous snake mostly distinguished by the presence of large eyes with round pupils on an oval-shaped head, a pair of internasals, undivided anal shield, and long hardy tail. The anterior part of the body is reddish in color, whereas the underparts are whitish in colors. This very common freshwater snake inhabits in several freshwater bodies including the land water interface of riverine ecosystem and feeds mostly on frogs, tadpoles, and small fishes. In water, it swims nimbly, but with vigor and after being disturbed, it can jump vigorously either to attack or to escape way. It is found in different places in India and even its neighboring countries (**Fig. 4.23**).

4.14.5.3.1.4 Badami Ghecho Shap, Betachra ***(Dendrelaphis tristis)***

This long (maximum length around **5** feet), thin, slender, dark brown-colored snake has a flat elongated head distinct from the head. The tail is around one-third of the total length of the snake. Usually black streak is present behind the eyes. This arboreal snake prefers to inhabit in moist deciduous forests and scrublands living on tree frogs, lizards, and small birds. They are distributed in the southern and eastern parts of India (**Fig. 4.23**).

Fig. 4.20 Some interesting species under the order Crocodilia of the class class Reptilia of Indian subcontinent
(**A**) Estuarine crocodile (*Crocodylus porosus*)
(**B**) Gharial (*Gavialis gangeticus*)
(**C**) Mugger (*Crocodylus. palustris*)

Fig. 4.21 Turtles and tortoises (Order Chelonia: Class Reptilia) of Indian subcontinent
(**A**) Olive ridley sea turtle in assemblage (*Lepidochelys olivacea*)
(**B**) Olive ridley sea turtle with marking (*Lepidochelys olivacea*)
(**C**) Black soft-shell turtle (*Nilssonia nigricans*)
(**D**) Median roofed turtle (*Pangshura tentoria*)
(**E**) Indian sawback (*Kachuga tecta*)
(**F**) Aldabra giant tortoise (*Aldabrachelys gigantea*)
(**G**) Leathery turtle (*Dermochelys coriacea*)

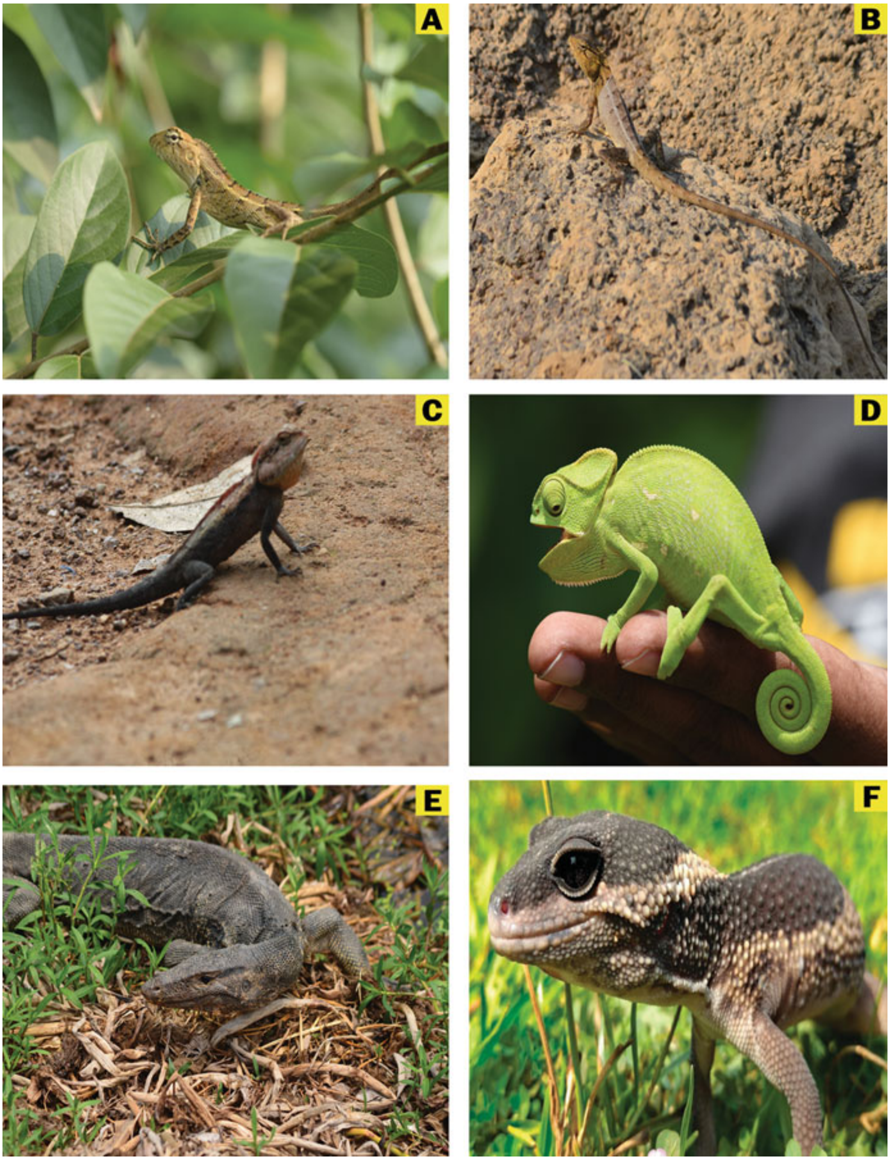

Fig. 4.22 Lizards (Order Lacetilia: Class Reptilia) of Indian subcontinent
(**A**) Common garden lizard (*Calotes versicolor*)
(**B**) Indian Rock lizard (*Psammophilus blanfordanus*)
(**C**) Fan-throated lizard (*Sitana ponticeriana*)
(**D**) Chameleon (*Chamaeleo zeylanicus*)
(**E**) Common Indian monitor (*Varanus bengalensis*)
(**F**) East Indian leopard gecko (*Eublepharis hardwickii*)

Fig. 4.23 Some unique representative of snakes (Order Ophidia : Class Reptilia) of Indian subcontinent
(**A**) Indian rock python (*Python molurus molurus*)
(**B**) Spectacled cobra (*Naja naja*)
(**C**) Jaldhora (*Xenochrophis piscator*)
(**D**) Common vine snake (*Ahaetulla nasuta)*
(**E**) Chiti (*Lycodon aulicus*)
(**F**) Slender coral snake (*Calliophis melanurus*)
(**G**) Badami Ghecho Shap, Betachra (*Dendrelaphis tristis*)

4.14.5.3.1.5 Common Vine Snake ***(Ahaetulla nasuta)***

This green-colored long (maximum length is more than **6** feet) and slender snake is characterized by pointed snout. Eyes are proportionately large with horizontal pupil. Its very tail is prehensile and cylindrical in shape. They inhabit in the bushes depicting cryptic coloration maintaining a fascinating turn over the foliage obtaining support from the twigs of plants. They are distributed mostly in the riparian forest tracts of the peninsular India and also in the eastern states of India (**Fig. 4.23**).

4.14.5.3.1.6 Slender Coral Snake ***(Calliophis melanurus)***

This small-sized, thin, cylindrical snake (maximum length little less than 3 feet) is with pale brown color over the body with slaty black tinge over the head. They are burrowing in habit and prefer to inhabit in the crevices under stones and other dumped solid substances. They are distributed mostly in the southern states and in the states of West Bengal and Odisha in the eastern India (**Fig. 4.23**).

4.14.5.3.2 Lizards (**Fig.** 4.22)

This important and widely distributed (about **4560** species across the world) group of reptiles belongs to the suborder Sauria or Lacertilia in the order Squamata. Many lizards marked with green and brown coloration remain concealed on the ground and often are provided with different body structures such as horns, crests, spikes, etc. The lizard like chameleons are also specialist tree climbers, and their flattened bodies help them to get more strength and stability while moving through the foliage. Most of the lizards with carnivorous feeding habit take foods (insects, spiders, worms, frogs, birds, and even small mammals) from their habitats and thereby play important roles in food chains and food webs.

4.14.5.3.2.1 Common Garden Lizard ***(Calotes versicolor)***

This lizard possesses large head having two distinct spines above the tympanum. Their body is laterally compressed with a fairly long tail. They are with brownish to grayish colors over the body with pale creamy colors on the underparts. Prominent dorsal crests are present from the neck to the end of the trunk. They feed on insects wandering over the bushes and forest undergrowth on the ground. They are distributed throughout India (**Fig. 4.22**).

4.14.5.3.2.2 Indian Rock Lizard ***(Psammophilus blanfordanus)***

This lizard is with dorsoventrally flattened body with comparatively large head, distinctly separated from the rest of the body. The scales are uniform and keeled. The brown-colored males become crimson colored during the time of breeding. They prefer to inhabit in the rocky area and lead an arboreal life, mostly living on insects. They are found in the central and eastern parts of India (**Fig.** 4.22).

4.14.5.3.2.3 Fan-Throated Lizard ***(Sitana ponticeriana)***

Their body is slender with a long tail and triangular head having a conical-shaped acute snout. Scales are keeled strongly on the lateral side of the body. Although their hind limbs are very developed, they do not possess the fifth toe. The males have a gular pouch below the throat. Their body color is brown with orange stripes on the outer sides of thighs. They mostly lead a terrestrial life on the rocky crevices with occasional climbing over the bushes. They occur in the dry deciduous forests of the eastern and peninsular India (**Fig.** 4.22).

4.14.5.3.2.4 Chameleon ***(Chamaeleo zeylanicus)***

As a unique form of arboreal lizards, chameleons are characterized by long extendable tongue with split end, moving rounded eyes, and a very specialized spring-like tail. They have the fascinating power of changing their body colors which normal state remains green. They can remarkably camouflage with the green leaves and tender branches of trees. They also use their extendible tongues to snatch the preys, especially the insects from a distance of more than 1 foot. Their fore and hind pairs of feet are modified to form clasping organs to ensure strong grip on the branches of the trees on which it resides (**Fig. 4.22**).

4.14.5.3.2.5 East Indian Leopard Gecko ***(Eublepharis hardwickii)***

This robust bodied gecko is featured with large head, distinct neck, short cylindrical tail having a nidge at the point of origin, and polygonal scales all over the head, but larger scales with tubercles the body. The color of the body is dark brown with transverse striations of light yellow colors (two on the body and four on the tail). This nocturnal and arboreal lizard inhabits in the dry deciduous forests of West Bengal, Odisha, Madhya Pradesh, and Bihar (**Fig.** 4.22).

4.14.5.3.2.6 Common Indian Monitor ***(Varanus bengalensis)***

This robust bodied lizard (body length **5.5** feet and tail length **3.5** feet) having gray brown color is characterized by the compressed tail and the presence of nostrils more nearer to the eye which open oblique slits. They live mostly in the scrublands near the forests of riverine networks and feed on fish, crabs, and insects including termites. They are distributed throughout India (**Fig.** 4.22).

4.14.5.3.3 **Crocodiles**

Out of the **22** species (**22**) of crocodiles of the world which belong to **3** families, only **3** occurs in India. This group of animals, largely because of their formidable and vicious appearance, has not endeared themselves to humanity. Surprisingly the peoples involved in fisheries and aquaculture activities too consider the crocodiles to be a liability to an aquatic ecosystem as they consume large quantities of fish. However, studies have indicated that crocodiles assist commercial fishery as they feed on large predatory fish like the **c**atfish, which in turn prey on the young or commercially valuable species. Also by preying on slow-moving and diseased fish, they keep fish population healthy and the water clean.

The World Wildlife Fund sponsored the Crocodile Bank in Madras, which was established with the objective of reestablishing Indian crocodile population and has now a large number of crocodiles big enough to be released in original crocodile habitat. But the Fisheries Department objects to this project in mistaken belief that the fish harvest will be reduced. It is time that our administrators sought sound ecological advice on such issues, or otherwise considerable conservation effort by nonofficial bodies is likely to be wasted. The following three aquatic crocodilian reptiles have become endangered.

4.14.5.3.3.1 Estuarine Crocodile ***(Crocodylus porosus)***

Although saltwater crocodile spends most of the time in its life cycle in brackish water, it prefers to descend down to freshwater riverine system for the purpose of breeding. Synchronization of the timing of breeding takes place in such a way so that the hatching of eggs takes place well into the wet season with the availability of plenty of foods such as aquatic insects, benthic invertebrates, and small fishes for the hatchlings to eat. Males are found to be more active busy prior to the breeding season to establish a territory to ensure hassle-free mating. Each female lays eggs in a nest mound and guards them for the next **3** months to help proper incubation. Several eggs are also lost after being swept away by floods and eaten by fish, water fowl, and other crocodiles and even taken by men. The fame carries the eight hatchlings (**200** mm) to water and guard them for a couple of weeks from the predation from birds, fish, frogs, and lizards, thereby enabling them to grow rapidly. Their sizes reach to a length of about **7–8** ft at the age of **6** years when they are mature to breed and on the large number of animals such as deers, wild boars, etc., These saltwater or estuarine crocodile is found in the mangroves of the states of Odisha and Sundarbans of West Bengal, India. Mugger was widely distributed, but its number has now greatly reduced due to indiscriminate hunting for its valuable hide (**Fig. 4.20**).

4.14.5.3.3.2 Mugger ***(C. palustris)***

It is the broad snouted and stocky crocodile which rarely attains a length of **3**th to **4** meters and is characterized by having four post-occipital scales on the neck (**Fig. 4.20**).

4.14.5.3.3.3 Gharial ***(Gavialis gangeticus)***

Gharials being the exclusive fish-eaters are characterized by having long narrow sword-like jaws. They are commonly found in almost all the major rivers like Brahmaputra, Ganges, and Mahanadi, but now it has sparse distribution and is found in large feeders in the Nepal, Tarai regions, Bihar, and Bengal in the Ganges River.

As the number of crocodiles has been greatly depleting and they are on the verge of extinction, a conservation project called "**Save the Crocodiles**" has been started in India which involves the incubation of eggs and rearing and release of the young ones in the preserves. Projects for the preservation of mugger, crocodiles, and gharials have been taken in the states of Telangana, Andhra Pradesh, Bihar, Gujarat, Kerala, Odisha, Rajasthan, Tamil Nadu, Uttar Pradesh, and West Bengal in India (**Fig.** 4.20).

4.14.5.3.4 Turtles and Tortoises (**Fig.** 4.21)

The turtles and tortoises belong to the order chelonian under the class reptilian. Around **295** species of chelonians that are present in the world belong to **14** families with some living on land and the rest in the water, either freshwater or seawater. The chelonians that live on land are called tortoises, whereas those in water are called turtles. More specifically turtles, those live in freshwater, are called terrapins. Chelonians reproduced by internal fertilization and eggs of all are laid in the moist land. Half of the Indian turtle species belong to the family Emydidae which differ from the tortoises (family Testudinidae) by their more or less flattened legs and webbed digits, in contrast to the relatively cylindrical limbs and distinctly separated digits of the tortoises. The turtles under the genus *Melanochelys* include six species of which the commonest one is *M. trijuga* that inhabit mostly in small ponds and similar water bodies but forage on land. They prefer to take the decomposed plant litters as their food. The genus *Cyclemys* includes two species, *C. mouhotii* and *C. dentata*, which both have an indistinct hinge across the under shell. One species, commonly known as Malayan box turtle, Cuora amboinensis, is found in the ponds and swampy areas, possessing a well-developed hinge on the dorsal side which separates its under shell into two movable lobes which can "**box up**" the turtle protectively making it unique. The genus *Kachuga* includes six species which are distributed in several rivers and wetlands of northern and eastern India. One of the largest species under the family Emydidae, *Batagur baska*, is an estuarine turtle that occurs in abundance in the mangrove–estuarine complex of Sundarbans, India. Out of so many sea turtles, the olive ridley sea turtle (*Lepidochelys olivacea*) needs special mention as this large-sized turtle nests on most of the shores in the eastern India in each year during late winter after making a migration from the Pacific Ocean crossing thousands of kilometers. Land tortoises, the most slow moving of all chelonians, belong to the genus of *Lepidochelys*, *Geochelone*, *Batagur*, *Platysternon*, *Lissemys*, *Melanochelys*, *Pelochelys*, *Trionyx*, *Chitra*, etc.

4.14.5.3.4.1 *Black Soft-Shell Turtle* ***(Nilssonia nigricans)***

This large-sized (maximum breadth is little more than whereas the length is little more than 2 feet) freshwater turtle normally found in the water bodies in the plain lands of Northern India and also in the Bangladesh. Earlier declared extinct, these turtles are being conserved in some temple ponds of North Bengal (Cooch Behar District) of the state West Bengal and Hayagriva Madhava Temple of the State of Assam, India. This black-colored turtle is characterized by having semiflexible shell of leathery texture to offer flexibility in movement. It has a tube-like structure protruding from the nose. This omnivorous species feeds various types of vegetable products (seeds, fruits, etc.) and small fish and other aquatic invertebrates (**Fig. 4.19**).

4.14.5.3.4.2 *Indian Mud or Flapshell Turtle* ***(Lissemys punctata)***

This soft-shelled turtle (maximum length around little less than **2** feet) is characterized by a pair of flaps at posterior region of plastron which hide the very small tail and hind legs. The dorsal surface of the carapace is bark olive black in colors ornamented with irregular blotches of yellow colors. Their head is oval terminating in tubular nostrils. The digits of the limbs are fully webbed. They are distributed in the Indo-Gangetic Plain.

4.14.5.3.4.3 *Olive Ridley Sea Turtle* ***(Lepidochelys olivacea)***

They are much larger than the freshwater turtle, having a carapace length of **3** feet. They are characterized by the presence of five or more costal shields on carapace. Their dorsal carapace surface is olive brown in color, but the color of the underparts is yellowish. Being omnivorous, they live on fish, benthic algae, and other crustaceans. Adults migrate long distance in the sea to settle down in the suitable ecological habitats (sandy shore with estuarine influence) to lay eggs (**Fig.** 4.21).

4.14.5.3.4.4 *Leathery Turtle* ***(Dermochelys coriacea)***

This turtle being the largest among the chelonians attains a size of around **5** feet with a weight of **400** kg. The shell is formed by strong cartilage overlying a number of small bones, and the whole body structure remains covered by smooth but tough skin. The entire body is supported by **12** longitudinal ridges (**7** above and **5** below), traversing from the back of the head to the initiation point of the tail. They feed on coelenterates and fishes of marine water. They have very restricted distribution and only are found in the Andaman and Nicobar Islands.

4.14.5.3.4.5 *Batagur Terrapin or River Terrapin* ***(Batagur baska)***

They represent one of the largest terrapins in India (maximum length is around **8** feet) and possess four claws on the forelimbs instead of five as possessed by other terrapins. It occurs mostly in the mangrove–estuarine ecosystems of Odisha and West Bengal, India.

Table 4.6 Orders and number of species of birds

Order	Living families	Living species
Sphenisciformes: penguins	1	15
Struthioniformes: ostriches	1	1
Casuariiformes: cassowaries, emus	2	4
Apterygiformes: kiwis	1	3
Rheiformes: rheas	1	2
Tinamiformes: tinamous	1	42
Gaviiformes: divers	1	4
Podicipediformes: grebes	1	17
Procellariiformes: albatrosses, fulmars, petrels	4	81
Pelecaniformes: tropic birds, pelicans, boobies, cormorants, anhingas, frigate birds	6	50
Ciconiiformes: herons, storks, flamingos, etc.	6	117
Anseriformes: screamers, swans, geese, ducks	2	149
Falconiformes: vultures, hawks, eagles, etc.	5	274
Galliformes: grouse, quails, turkeys, etc.	7	250
Gruiformes: cranes, rails, coots, bustards, etc.	12	185
Charadriiformes: jacanas, plovers, sandpipers, stilts, gulls, terns, auks, etc.	16	293
Columbiformes: sandgrouse, pigeons	2	301
Psittaciformes: parrots, parakeets, cockatoos, lories, lorikeets, macaws, lovebirds	1	317
Cuculiformes: toracos, cuckoos	2	143
Strigiformes: owls	2	132
Caprimulgiformes: frogmouths, nightjars	5	92
Apodiformes: swifts, hummingbirds	3	388
Coliiformes: mouse-birds	1	6
Trogoniformes: trogons	1	35
Coraciiformes: kingfishers, todies, motmots, bee-eaters, rollers, hoopoes, hornbills	10	192
Piciformes: barbets, honey guides, puffbirds, jacamars, toucans, woodpeckers	6	377
Passeriformes: flycatchers, larks, swallows, wrens, thrushes, warblers, sparrows, etc.	55	5110
Totals	155	8580

4.14.5.3.4.6 Indian Sawback ***(Kachuga tecta)***

This small-sized (maximum length **8** inches) terrapin is found in large abundance in river basins of Indus, Ganges, and Brahmaputra. The keel at the dorsal side of the body traverses backwards and ends by converting into a pointed spine. The color of the carapace is olive green with small black spots. The color of the head is black on the upper side and yellow in the lower part. This herbivorous animal feeds on the algae and macrophytes. They have the ability to move forward after retracting the head and forelimbs within the body while using the hand limbs to push and propel forward through the water (**Fig. 4.21**).

*4.14.5.3.4.7 Aldabra Giant Tortoise **(Aldabrachelys gigantea)***

This represents the largest tortoise of the world. Western Indian Ocean islands and Madagascar are the homeplace of this interesting creature of the world. The carapace is slaty black in color. It possesses stout, stocky, and heavily rigid legs to carry the heavy weight of the body. The remarkably long neck of this tortoise helps the animal to harvest the leaves and twigs of the trees as food. Their vigorous foraging behaviors dislodge the habitats and cause falling of trees and thereby enable the other associated fauna in its community to utilize the resource bases (**Fig. 4.21**).

*4.14.5.3.4.8 Median Roofed Turtle **(Pangshura tentoria)***

This small-sized freshwater turtle (**10** inches) belongs to the family Bataguridae and is distinguished by unpatterned pale olive colored elliptical-shaped elevated carapace, while the color of the plastron is having yellow tinges (**Fig. 4.21**). The head is short with blunt snout. This sluggish natured solitary turtle is found to inhabit in the shallow water wetlands near the agricultural fields from it harvests own food materials (aquatic plants and animals) and breeds during late winter to early summer months.

4.14.6 Uniqueness and Diversity of Birds

Birds, most beautiful, attractive, admired, entertaining faunal group of the world, not only make the life of human beings meaningful but also play important roles in maintaining natural balance of the human environment. They display tremendous power of adaptability. Many flourish through great adaptability which have made it possible their wide range of distribution in allmost all the nook and corners of the world. Despite having most enviable mobility, birds have become very much threatened faunal components because of ongoing environmental perturbations. About a century ago, the noted naturalist, T.H. Huxley, designated "**birds**" as "**glorified reptiles**" mainly because of the possession of a number of unique characteristics of reptiles in birds, such as certain skeletal and muscular features, similar eggs, an "**egg tooth**" on the upper jaw at hatching time, etc. But the most striking feature that sets the birds apart from all other animals is the acquisition of feathers in birds as for protection and as aid for the flight (King 1981; Martin, 1987) .

4.14.6.1 Characteristics and Classification of Birds

4.14.6.2 Biological Characteristics and Global Status of Avifauna

The principal features of birds include feathers, wings, and beaks, which together make birds as the most easily classifiable and identifiable of all animal classes. Bats, another winged mammal, differ from the birds in having teeth and fur on the wings. Many of the world's **8580** bird species are flagging as they struggle against a deadly mixture of often human-caused threats. However, many of the bird species are now under the threats of their extinction and as per a study conducted by the global alliance of conservation organizations, called BirdLife International almost **1200** species representing about **12%** of the world's remaining bird species may face extinction within the next century. Although some bird extinctions now seem imminent, many species can still be saved provided we commit to bird conservation as an integral part of a sustainable development strategy. For many reasons, such a commitment would be in humanity's best interests.

4.14.6.3 Classificatory Scheme of the Class Aves

To date, almost **8580** species of living birds have been recorded across the globe which are placed in **27** orders and **155** families based on their many and varied degrees of anatomical differences and similarities. All of the **1300** species of birds belonging to the class Aves so far recorded from the Indian subcontinent (Ali and Ripley 1983; Kazmierczak 2000) which is further divided into two subclasses and **20** orders. Each order is subjected to further division into families, which contain similar genera made up of birds of related species. Their distribution is universal, and variability of marked diversity among different groups is traced by their structural and behavioral adaptations as imposed by environment and other extraneous circumstances.

(**1**) Ostriches (**order Struthioniformes**, with **1** family and **1** species); (**2**) rheas (o**rder Rheiformes**, with **1** family and **3** species); (**3**) emus and cassowaries (**order Casuariiformes**, with **2** families and **4** species); (**4**) kiwis (**order Apterygiformes**, with **1** family and **3** species); (**5**) tinamous (**order Tinamiformes**, with **1** family and **42** species); (**6**) penguins (**order Sphenisciformes**, with **1** family and **15** species); (**7**) divers and loons (**order Gaviiformes**, with **1** family and **4** species); (**8**) grebes (**order Podicipediformes**, with **1** family and **17** species); (**9**) albatrosses, fulmars, shearwaters, and petrels (**order Procellariiformes**, with **4** families and **81** species); (**10**) pelicans, cormorants, boobies, frigate birds (**order Pelecaniformes**, with **6** families and **50** species); (**11**) herons, storks, egrets, etc. (**order Ciconiiformes**, with **6** families and **117** species); (**12)** ducks, geese, screamers, swans, etc. (**order Anseriformes**, with **2** families and **149** species), (**13)** birds of prey, eagles, vultures, falcons, hawks, etc. (**order Falconiformes**, with **5** families and **274** species); (**14)** gallinaceous birds, such as pheasants, peacock, turkeys, partridge, grouse, megapodes, curassows (**order Galliformes**, with **7** families and **250** species); (**15**) cranes, bustards, coots, and rails (**order Gruiformes**, with **12** families and **185** species); (**16**) waders, jacanas, plovers, sandpipers, stilts, terns, auks, and gulls (**order Charadiiformes**, with **16** families **293** species); (**17**) sand grouse and pigeon (**order Columbidae**, with **2** families and **301** species); (**18**) parrots, parakeets, cockatoos, lories, lorikeets, macaws, and lovebirds (**order Psittaciformes**, with **1** family and **317** species); (**19**) cuckoos and toracos (**order Cuculiformes**, with **2** families and **143** species); (**20)** owls (**order Strigiformes**, with **2** families and **132** species); (**21**) nightjars, oilbirds, frogmouths, potoos, and others (**order Caprimulgiformes**, with **5** families and **92** species); (**22**) swifts and hummingbirds (**order Apodiformes**, with **3** families and **388** species): (**23**) colies and mousebirds (**order Coliiformes**, with **1** family with **6** species); (**24**) trogons (**order Trogoniformes**, with **1** family and **35** species); (**25**) kingfishers, bee-eaters, todies, motmots, rollers, hoopoes, hornbills (**order Coraciiformes**, with **10** families and **192** species); (**26**) woodpeckers, barbets (**order Piciformes**, with **6** families and **377** species); (**27**) perching birds (**order Passeriformes**, with **55** families and **5110** species) (**Figs. 4.13, 4.14, 4.15, 4.16, 4.17, 4.18, 4.19, 4.20, 4.21, 4.22, and 4.23**)

4.14.6.4 Evolution and Relationships Among Birds

Therefore, a total of **8580** living species of birds belonging to **27** orders and **155** families are in existence across the world. Evolution being a fluid process having initially two-dimensional directions which later gives off many branches, some of which dying off while others reaching out in all directions, continues to modify and grow. Descended **140** million years ago from reptilian stock similar to that which produced the dinosaurs, birds have radiated explosively over the earth. They show a wide variety of sizes, shapes, colors, and habits. They live in every continent and occupy almost every conceivable niche. Some even nest underground. The **8580** species of birds on earth today represent the growing end of evolutionary branches as being the separate entities, populations that for one reason or another have been broken down into some that normally do not or cannot breed with each other. They are reproductively isolated. This large galaxy of living species has been arranged by systematists into **27 l**iving orders of birds, and these in turn have been broken down into **155** families. Several of the lower orders of birds cannot fly like the ostriches, the rheas, the cassowaries and emus, the kiwis, and the penguins. This gave rise to a theory that modern birds did not all come from a common ancestor but represented by two lines of descent: first, one that had long ago attained flight and second, one that is not yet off the ground.

Modern birds, adapting and changing during the last **100** million years, have filled virtually every available niche in the world. About **120** living species of "**long-legged waders**" have evolved. These birds like the herons, storks, ibises, and related birds have silt-like legs for stalking the shallows and long compensating necks, making their living catching small fish, frogs, and other forms of aquatic life. Bills take a variety of shapes such as dagger-like or spear-like upturned, downturned, shoe-like, and even spoon-like. The most specialized of all the wading birds are the colorful flamingos. Their goose-like cries, their goose-like young, their molts, and even their feather parasites suggest an affinity with geese. Certainly they have evolved unique specialization in their way of evolving grotesquely exaggerated necks and legs and thick, bent bills equipped with fringed lips for straining edible organisms from the soup-like mud in which they wade. Oriental species of birds having efficient adaptability to the various habitats encircling this deciduous forest belt include pheasants, grouse, gallus alongside golden orioles, robins, rollers, etc. and on the plains of the river valleys a mixed population of storks, kingfishers, bustards, partridges, cranes, herons, egrets, pied harriers, teals, ducks, etc.

The waterfowl, the familiar web-footed swimmers which form the sportsman's game, include ducks, geese, and swans. The distinctive feature that most of the **149** species under the order Anseriformes have in common is a flattish "**duck**" bill, although the mergansers or fish ducks are equipped with saw-like mandibles. Some ducks dabble; others dive for a living, while swans, with necks longer than their bodies, dip or tip up for their diet of aquatic plants. Geese, shorter-necked, also do this but primarily graze on land for grass and roots.

Among the most spectacular of all groups are the birds of prey. Superbly designed for their predatory task, they are powerful fliers, capable of effortless soaring or plunging bursts of speed. The **274** living species under the order Falconiformes have hooked beaks for tearing flesh, and those which take living prey characteristically have strongly hooked talons. Vultures, those naked-headed birds of prey which feed on carrion, have weaker feet as an obvious adaptation, since their prey cannot escape. Owls, though nocturnal birds of prey, are not included in this order.

The fowl-like birds, numbering about **250** loving species under the order Galliformes, embrace the grouse, turkeys, quails, partridges, pheasants, guans, etc. They are sturdy ground birds, with grubbing bills and stout, scratching toes. Some are among the world's most gorgeous birds; others, notably the domestic fowl, are among the most economically important.

A total of **185** species including the cranes, rails, coots, bustards, and other related birds belong to an order Gruiformes that for convenience are designated as "**marsh birds**." The cranes are stork-like, whereas rails and coots are more like hens and hide in the reeds. The bustards are heavily-bodied walking birds of treeless plains. All birds of ancient lineage may be losing the fight for survival (Figs. 4.24, 4.25, 4.26, 4.27, 4.28, 4.29, 4.30, 4.31, 4.32, and 4.33).

The shore birds, gulls, and auks from another order also united because of internal anatomical similarities. The birds of this multifarious assemblage numbering nearly **300** species under the order Charadriiformes are highly gregarious and are to be found more widely throughout the world than any other group. The shore birds are small- to medium-sized waders that flock along the margins of water ways and the ocean. The gulls and terns are graceful aerialists. Auks fit the same niche in northern seas that penguins do in the Southern Hemisphere, but have not lost their power of flight. Indeed, they have double-purpose wings which enable them to fly through the air and under the water as well. Four-fifths of the world's living birds are made up of the various orders of land birds, which seem to have had their greatest development

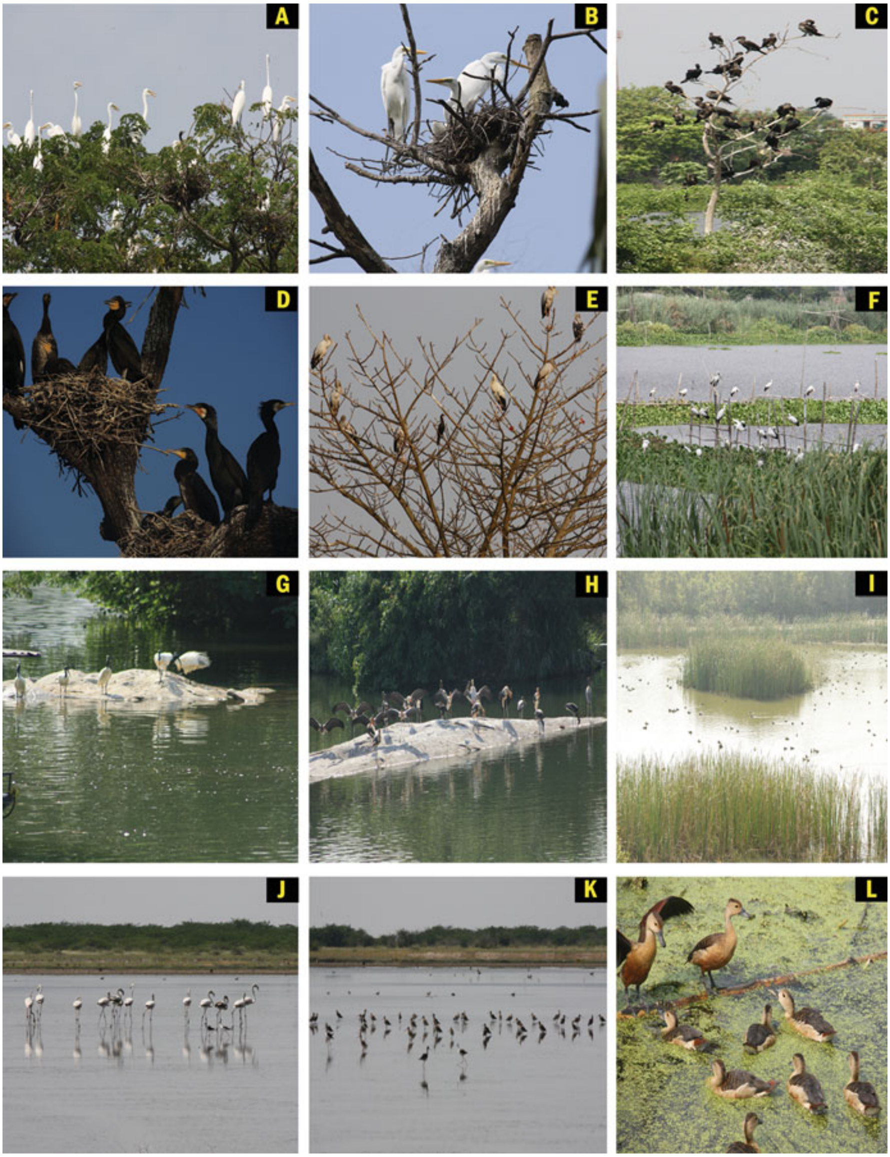

Fig. 4.24 Birds in colony from variety of riparian forests of Indian subcontinent
(**A**) Colony of large egret (*Casmerodius albus*)
(**B**) Nesting of large egret (*Casmerodius albus*)
(**C**) Colony of little cormorant (*Phalacrocorax niger*)
(**D**) Colony of great cormorant (*Phalacrocorax carbo*)
(**E**) Colony of Asian openbill stork on large trees (*Anastomus oscitans*)
(**F**) Colony of Asian openbill stork on macrophytes on wetlands (*Anastomus oscitans*)
(**G**) Colony of black-necked stork (*Ephippiorhychus asiaticus*)
(**H**) Colony of European white-necked stork (*Ciconia episcopus*)

in recent geological time. The worldwide pigeons, for example, and the Old World sandgrouse, with their small-headed, short-legged look, total more than **300** living species under the order Columbidae. They are the only birds able to suck up water when drinking; all other species have to tip their heads up to let the water flow down their throats.

The gaudy parrots, which come in all the colors of the rainbow, are big headed with deep, hooked beaks, and dexterous, prehensile feet. Living for the most part throughout the tropics, they number **317** living species under the order Psittaciformes. Not far removed from them anatomically but quite different in shape are the worldwide cuckoos and the turacos of Africa, slim-bodied birds with long-tails. The birds like cuckoos and turacos are grouped together to be included under the order Cuculiformes accommodating **143** species. Owls were once classified with the hawks because of their hooked beaks and curved talons, but they are actually unrelated to those predatory birds. Rather they furnish another good example of convergent evolution, birds of separate origin developing similar features because of their way of life. Owls takeover the night shift from the day-flying hawks and are best characterized by their loose feathering, large heads, and large, forward-facing eyes framed by round facial discs. Nearly worldwide, they number **132** species under the order Strigiformes.

A total of **92** species under the order Caprimulgiformes of nocturnal birds, which includes nightjar and fern owl, possess fluffy, owl-like plumage, but with considerably degenerated beaks. They are considered as flying insect traps, capturing their quarry in cavernous gaping mouths. The most aerial of birds are the swifts, sabre-winged, swallow-like birds that spend all their active hours in the open sky. As in the nightjars, beaks and feet have atrophied to near uselessness. Most systematists lump the swifts in the swim order as the hummingbirds, pointing out that they branched off the same stem. A total of **388** species of the tiniest of all birds having gem-like, needle-billed hummers, under the order Apodiformes are found mostly in the New World, whereas Old World group has ever become as efficient for nectar feeding.

The kingfishers and their allies are distinguished by their feet, which are designated as "**syndactyl**," having the front toes joined for part of their length. The kingfishers with their spear-like bills are very common features of most of the water bodies of the world. This charismatic avian group together with another colored group of birds, such as the tiny handsome bee-eaters, the rollers, and the hoopoes of the Old World and the huge, bizarre hornbills of the Old World tropics reveal a diversity of **192** species under the order Coraciiformes residing on the holes of earth or trees as their nests on the bank of water bodies. The woodpeckers and their allies, numbering **377** species under the order Piciformes, are also nesters in holes and include such dissimilar families as the barbets with their whiskery bills. None, however, can compare with the passerines or perching birds. The fascinating

Fig. 4.24 (continued) (**I**) Colony of lesser whistling teal (*Dendrocygna javanica*)
(**J**) Colony of flamingo (*Phoenicopterus roseus*)
(**K**) Colony of fantail snipe (*Gallinago gallinago*)
(**L**) Colony of tufted pochard (*Aythya fuligula*)

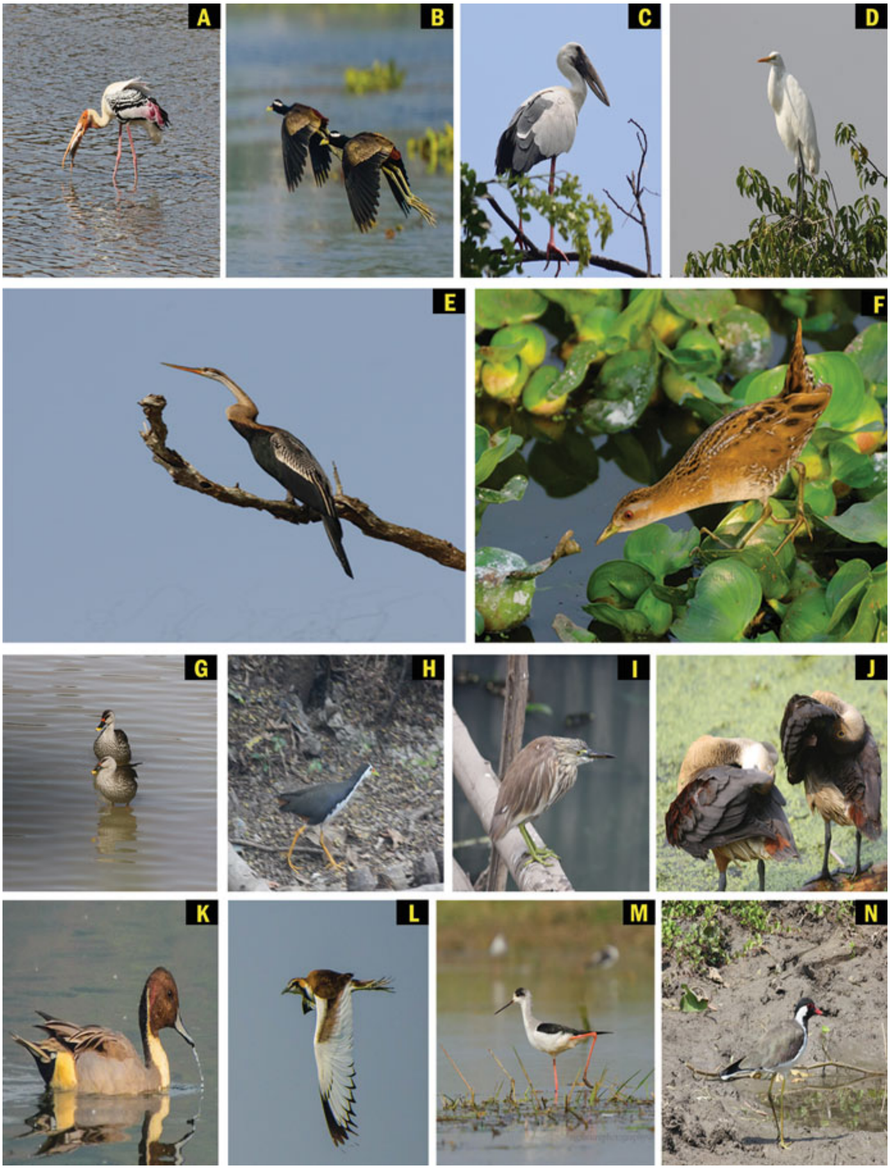

Fig. 4.25 Aquatic birds of Indian subcontinent
(**A**) Painted stork (*Mycteria leucocephala*)
(**B**) Bronze-winged jacana (*Metopidius indicus*)
(**C**) Openbill stork (*Anastomus oscitans*)
(**D**) Median egret (*Mesophoyx intermedia*)
(**E**) Darter or snake bird (*Anhinga rufa*)
(**F**) Baillon's crake (*Porzana pusilla*)
(**G**) Spot-billed or gray duck (*Anas poecilorhyncha*)

order Passeriformes with roughly **5110** species under **55** families represents the largest group of birds (three-fifths of all the world's birds) displaying considerable ranges in size and beauty from tiny tailor birds to large, gorgeous birds of paradise and has developed themselves as most hardy adaptive group in relatively recent times. This is the period when some ancient group of birds such as the ostriches, pelicans, cranes, and like are on the way out, and the Passeriformes are supposed to become the most "**evolved**" of all the birds sustaining the ongoing environmental perturbations caused by human beings.

4.14.6.5 Major Groups of Birds Having Their Own Structural and Functional Uniqueness

4.14.6.5.1 Birds of Preys: Bioagents Facilitating Ecological Stability

The term "**bird of prey**," having its origin from a Latin word *rapture* (literally means "**to seize and carry away**"), mainly includes a number of bird species (vultures, hawks, falcons, kites, buzzards, harriers, eagles, etc.) under the order Falconiformes (Figs. 4.34 and 4.35). This very unique avian order includes five different families: (1) Cathartidae (**7** extinct species under **5** genera: New World vultures), (2) Pandionidae (**1** species, *Pandion haliaetus*), (3) Accipitridae (**14** subfamilies and **233** species, Jerdon's baza (*Aviceda jerdoni*), Oriental honey buzzard (*Pernis ptilorhynchus*), black kite (*Milvus migrans*)), (4) Sagittariidae (**1** species, endemic to Africa, *Sagittarius serpentarius*), and (5) Falconidae (around **60** species, white-bellied sea eagle, (*Haliaeetus leucogaster*), crested serpent eagle (*Spilornis cheela*), Indian white-backed vulture (*Gyps bengalensis*), eastern marsh harrier (*Circus spilonotus*), crested goshawk (*Accipiter trivirgatus*), shikra (*Accipiter badius*), besra (*Accipiter virgatus*), common buzzard (*Buteo buteo*), collared falconet (*Microhierax caerulescens*), collard falconet (*Microhierax caerulescens*), common kestrel (*Falco tinnunculus*), red-headed falcon (*Falco chicquera*), peregrine (*Falco peregrinus calidus*)). Out of these five families, two, Sagittariidae and Pandionidae, are not found in India. All other species under this category of avifauna utilize suitable available habitats of Indian subcontinent living on a diversity of prey which include insects, fish, amphibians, small birds, reptiles, and mammals. A number of species of vultures act as scavengers feeding on the carcasses of large animals such as cows, buffaloes, and even dead elephants. Different raptor species have evolved

Fig. 4.25 (continued) (**H**) White-breasted water hen (*Amaurornis phoenicurus*)
(**I**) Indian pond heron (*Ardeola grayii*)
(**J**) Tufted pochard (*Aythya fuligula*)
(**K**) Northern pintail (*Anas acuta*)
(**L**) Pheasant-tailed jacana (*Metopidus indicus*)
(**M**) Black-winged stilt (*Himantopus himantopus*)
(**N**) Red-wattled lapwing (*Vanellus indicus*)

Fig. 4.26 Surface wandering birds of Indian subcontinent
(**A**) Bluethroat (*Erithacus svecicus*)
(**B**) Hoopoe (*Upupa epops*)
(**C**) Red jungle fowl (*Gallus gallus*)
(**D**) Yellow-breasted wagtail (*Motacilla flava*)
(**E**) Gray wagtail (*Motacilla cinerea*)
(**F**) White wagtail (*Motacilla alba*)
(**G**) Eurasian curlew (*Numenius madagascariensis*)

independently through natural selection by developing and manifesting varied form of adaptive strategies to lead a successful predatory mode of life and to utilize the available biomes, habitats, and niche (Naoroji 2006).

Raptors being the predators enjoy the position at the top of the food web and thereby act as an important determinant of the ecosystem functioning by controlling the population of amphibians, reptiles, birds, and mammals and thereby function as indicator of the ecological health of their own ecosystem (Fig. 4.36).

4.14.6.5.2 **Kingfisher in India**

The avifaunal group kingfisher under the family Alcedinidae of the order Coraciiformes includes some brightly colored birds enjoying cosmopolitan distribution where most of the species out of **114** species are found to inhabit in the tropical regions. The members of this avifaunal group is characterized by having wonderful colored plumage making them very attractive and with lot of aesthetic appeals, proportionately large head with long and pointed bills, blunt tail, and short legs. They spend most of their time sitting and perching quietly on any hard structure over or near the water bodies including rivers and very efficiently catch their preys, mostly fish, by swooping down from a perch. (**12**) species occur in India, namely, common kingfisher (*Alcedo atthis*), blue-eared kingfisher (*Alcedo meninting*), black-capped kingfisher (*Halcyon pileata*), white-breasted kingfisher (*Halcyon smyrnensis*), pied kingfisher (*Ceryle rudis*), Oriental dwarf kingfisher (*Ceyx erithacus*), collared kingfisher or mangrove kingfisher (*Todiramphus chloris*), **ruddy kingfisher** (*Halcyon coromanda*), crested kingfisher (*Megaceryle lugubris*), Blyth's kingfisher (*Alcedo hercules*), brown-winged kingfisher (*Halcyon amauroptera*), and stork-billed kingfisher (*Halcyon capensis*).

4.14.6.5.3 **Owls in India**

Out of **150** owl species all over the world, **34** species of owls are found to occur in India. This unique nocturnal avifauna although functions like the "**birds of prey**" belongs to a separate order, Strigiformes, instead of belonging to the order Falconiformes. This avifaunal group display lot of color variations. Owls are solitary creatures, who sleep all day and prowl at night. They inhabit in almost all ecological habitats in the riparian forests. These birds with their predatory efficiencies control

Fig. 4.26 (continued) (**H**) Emerald dove (*Chalcophas indica*)
(**I**) Lesser sand plover (*Charadrius mongolus*)
(**J**) Small pratincole (*Glareola lactea*)
(**K**) Wood sandpiper (*Tringa glareola*)
(**L**) Jungle prinia (*Prinia sylvatica*)

Fig. 4.27 Owls and owlets of Indian subcontinent
(**A**) Brown Fish Owl (*Ketupa zeylonensis*)
(**B**)Spotted Owlet (Adult) (*Athene brama*)
Spotted Owlet (*Athene brama*) within tree hole
(**C**) Spotted Owlet (Juvenile)(*Athene brama*)

profusely the population of rodents and thereby render benefit to the human beings by saving agricultural products and also controlling disease outbreaks from the rodents.

4.14.6.5.4 Vulture: Diversity and Conservation in India

Vultures as being the large and competent raptors are referred to as nature's sweepers due to their efficient roles as scavengers consuming and thereby cleaning the carcasses of large members of Bovidae (ruminants) and even the elephants. Out of nine species of vultures, viz., (**1**) **white-rumped vulture (*Gyps bengalensis*), (2)** Indian vulture (*Gyps indicus*), (**3**) slender-billed vulture (*Gyps tenuirostris*), (**4**) Himalayan griffon (*Gyps himalayensis*); (**5**) Egyptian vulture (*Neophron percnopterus*), (**6**) red-headed vulture (*Sarcogyps*), (**7**) Eurasian griffon (*Gyps fulvus*), (**8**) cinereous vulture (*Aegypius monachus*), and (**9**) bearded vulture (lammergeier) (Gypaetus barbatus), three species of vulture (white-rumped vulture, Indian vulture, and slender-billed vulture) have been severely threatened and listed in the **IUCN** Red List as critically endangered species in the year 2002. Although the population density of other species have been dwindling considerably, they were not affected that much, due to a number of factors, including their migratory nature and the location of habitats in more remote and forested areas.

4.14.6.5.5 Threatened Avifauna in India: Criteria for Different Conservation Categories

Out of so many conservation categories, a species is considered as **extinct (E)** when there exists no doubt about total disappearance of the said species from the earth. But a species is considered as **extinct in the wild** (EW) when a species becomes extinct from the natural environment but still exists in the captivity or survive in cultivation or as a natural populations well outside its past range of occurrence. A species is **critically endangered (CE)** when it is facing an extremely high risk of extinction in the wild in the immediate future, as defined by any of the criteria such as (**1**) rapid population reduction [(reduction >**80%** in **10** years or **3** generations, decline >**50%** in **10** years or **3** generations **(EN)**, decline >**20%** in **10** years or **3** generations **(VU)**]; (**2**) small range and fragmented, declining or fluctuating (extent of occurrence estimated <**100 km^2** (CR), extent of occurrence estimated <**5000 km^2**, extent of

Fig. 4.27 (continued) (**D**) Spotted Owlet (Medium sized) (*Athene brama*)
(**E**) Assian Barred Owlet (*Glaucidium cuculoides*)
(**F**) Brown Hawk Owl (*Ninox scutulata*)
(**G**) Barn Owl (*Tyto alba*)
(**H**) Jungle Owlet with Catch (*Glaucidium radiatum*)

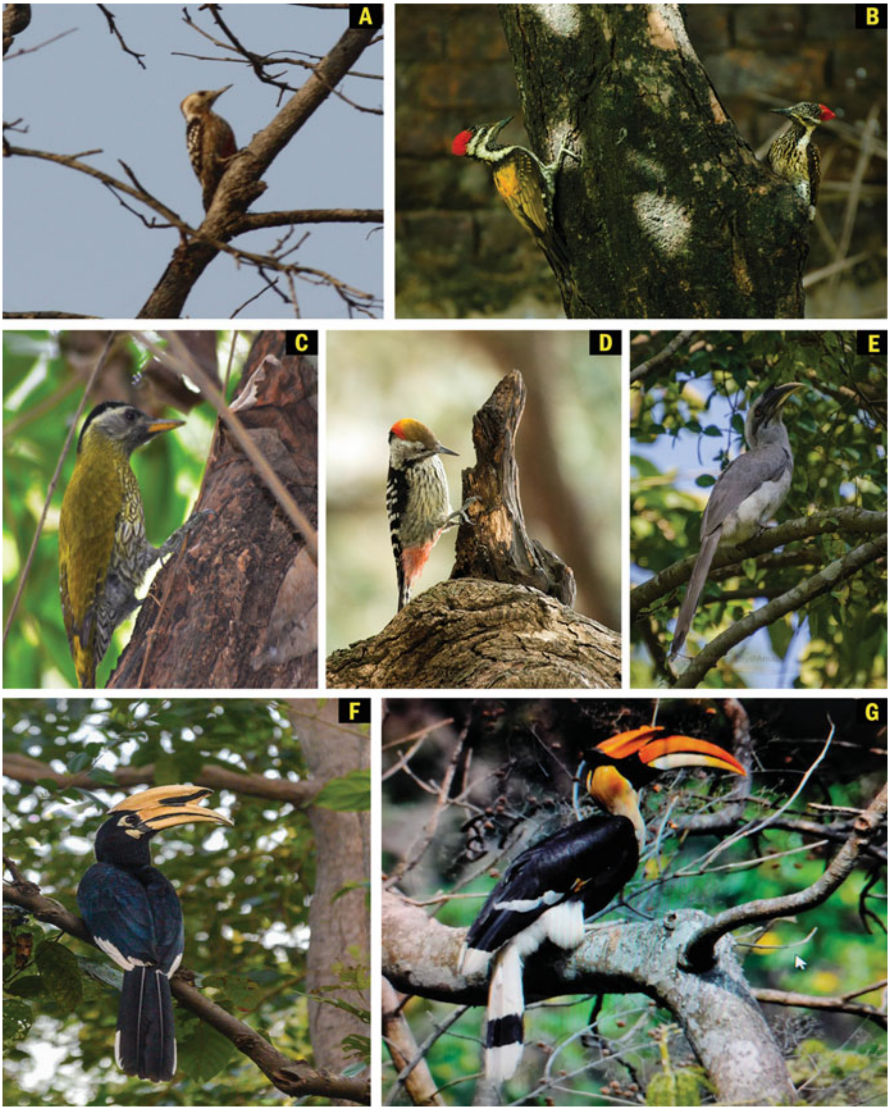

Fig. 4.28 Some common species of Woodpeckers and hornbills of Indian subcontinent
(**A**) Fulvous breasted woodpecker (*Dendrocopos macei*)
(**B**) Lesser Golden -backed Woodpecker (*Dinopium javanense*)
(**C**) Streak throated woodpecker (*Picus xanthopygaeus*)
(**D**) Brown Fronted Woodpecker (*Dendrocopos auriceps*)
(**E**) Indian Gray Hornbill (*Tockus birostris*)
(**F**) Oriental Pied Hornbill (*Anthracoceros albirostris*)
(**G**) Great Pied Hornbill (*Buceros bicornis*)

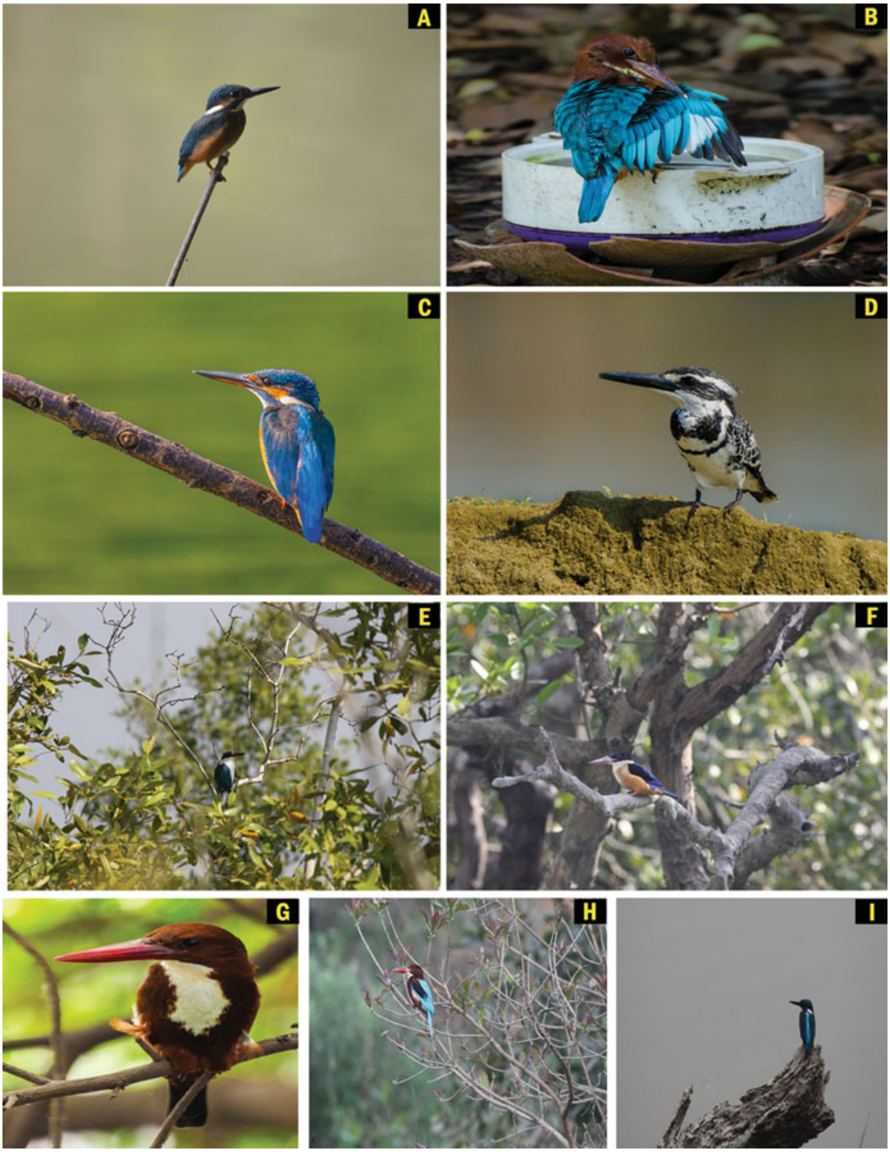

Fig. 4.29 Diversity of kingfisher of Indian subcontinent
(**A**) Small blue kingfisher (*Alcedo atthis*)
(**B**) White-breasted kingfisher (*Halcyon smyrnensis*)
(**C**) Common blue-eared kingfisher (*Alcedo meninting*)
(**D**) Pied kingfisher (*Ceryle rudis*)
(**E**) White-breasted kingfisher (*Halcyon smyrnensis*)
(**F**) Collard kingfisher (*Todiramphus chloris*)
(**G**) Ruddy kingfisher (*Halcyon coromanda*)
(**H**) Oriental dwarf kingfisher (*Ceyx erithacus*)
(**I**) Blue-eared kingfisher (*Alcedo meninting*)

Fig. 4.30 Some rare species of vulture species of Indian subcontinent
(**A**) Indian white-backed vulture (*Gyps bengalensis*)
(**B**) Himalayan griffon vulture (*Gyps himalayensis*)
(**C**) Folk of Himalayan griffon vulture (*Gyps himalayensis*)
(**D**) Eurasian griffon (*Gyps fulvus*)
(**E**) Folk of slender-billed vulture (*Gyps indicus*)

occurrence <**20,000 Km**^{2} (VU); (**3**) small population and declining [(decline of population > **25%** in **3** years or **1** generation (**CR**), decline >**20%** in **5** years or **2** generations **(EN)**, decline >**10%** in **10** years or **3** generations (**VU**)]; (**4**) very small population with small range [(population < **50** mature individual (**CR**) with the occupancy of <**100 km**^{2}, population < **250** mature individuals **(EN)** with the occupancy of <**100 km**^{2}, and population < **1000** mature individuals (**VU**) with the area of occupancy <**100 km**^{2}]; and (**5**) analysis of probability (probability of extinction in the wild is >**50%** in **10** years or **3** generations (**CR**), probability of extinction in the wild >**20%** in **20** years or **5** generations **(NE)**; probability of extinction in the wild is >**10%** in **100** years **(VU)** (BirdLife International 2001;

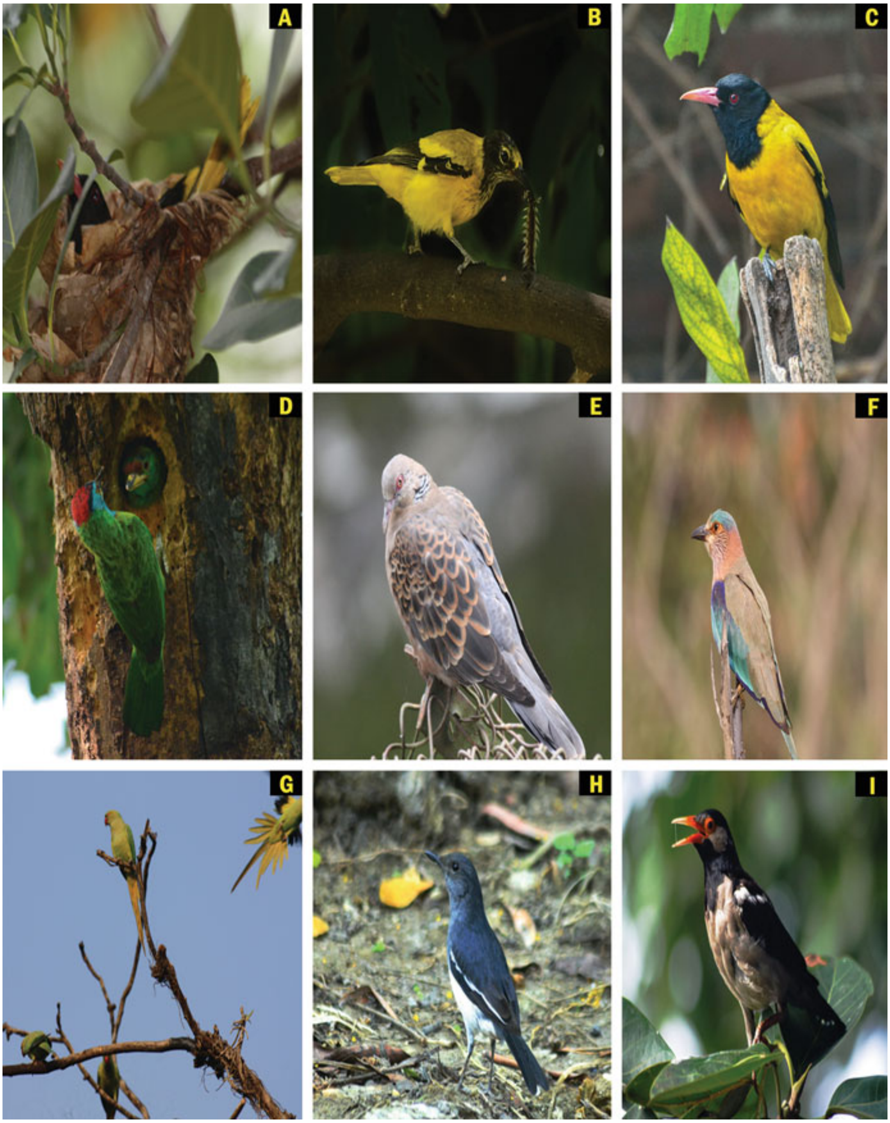

Fig. 4.31 Medium-sized birds of prey of Indian subcontinent
(**A**) Black-headed oriole in nest (*Oriolus xanthornus*)
(**B**) Black-headed oriole (*Oriolus xanthornus*) in the developing stage preying insect larvae
(**C**) Adult black-headed oriole (*Oriolus xanthornus*)
(**D**) Blue-throated barbet (*Megalaima asiatica*)
(**E**) Spotted dove (*Streptopelia chinensis*)
(**F**) Indian roller (*Coracias benghalensis*)
(**G**) Rose-ringed parakeet (*Psittacula krameri)*
(**H**) Indian blue robin (*Luscinia brunnea*)
(**I**) Pied myna (*Sturnus contra*)

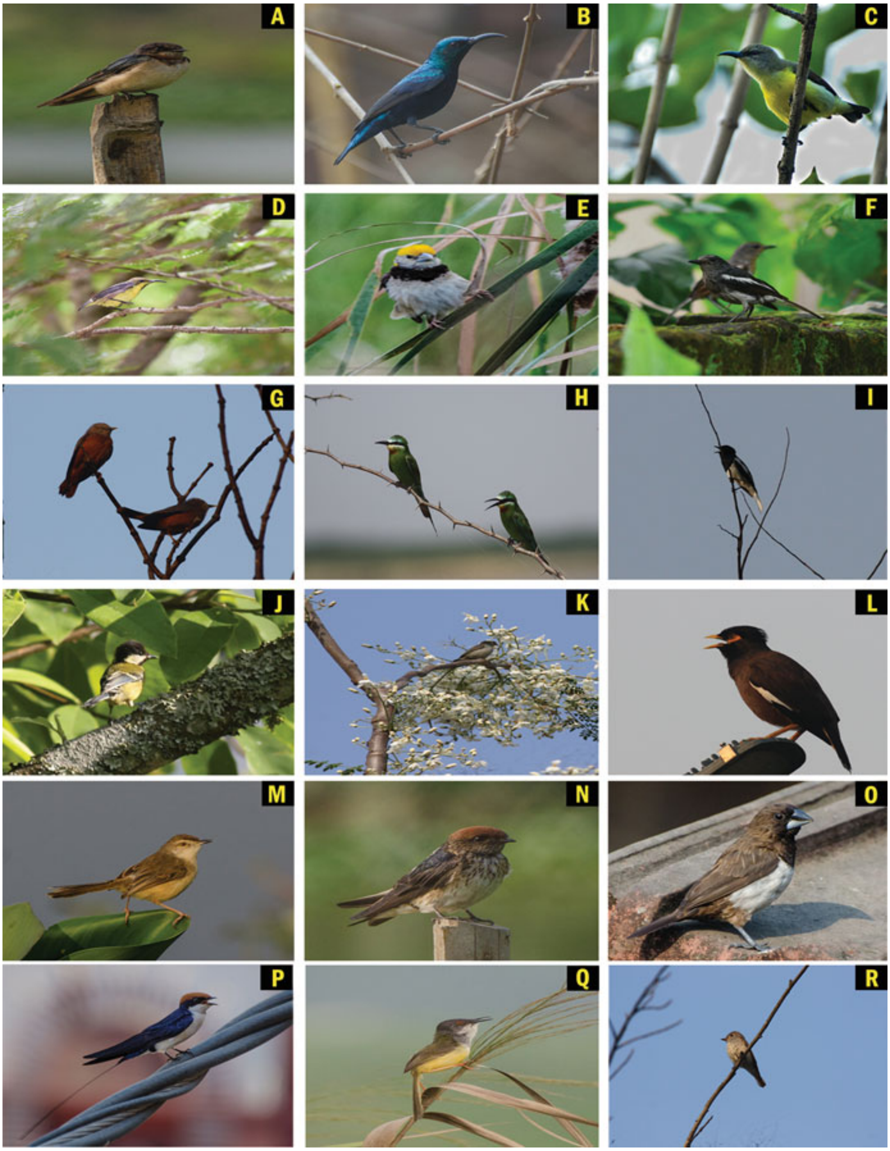

Fig. 4.32 Small perching birds of Indian subcontinent
(**A**) House swallow (*Hirundo rustica*) Barn Swallow
(**B**) Purple sunbird (*Nectarinia asiatica*)
(**C**) Purple rimped sunbird (*Nectarinia zeylonica*)
(**D**) Little spiderhunter (*Arachnothera longirostra*)
(**E**) Black Breasted Weaver (*Ploceus bengalensis*)
(**F**) Oriental Magpie robin (*Copsychus frontale*)
(**G**) Chestnut Tailed Starling (*Sturnus malabaricus*)
(**H**) Green Bea eater (*Meropis leschenaultia*)

Naoroji 2006). An **endangered species (E)** is also at the high risk of extinction in the wild within a short period if the causative stress factors continue to operate on them. Based on the intensity of imposition of different stress factors and threating criteria, the probability of assigning and including the species in this category may vary across different eco-regions of the world. When a species is neither a **critically endangered** (**CE**) nor **endangered (E)**, but is facing a very high risk of extinction in the wild in the near future, it is assigned with the conservation status as **vulnerable**. Besides, other least threatened categories are (**1**) near threatened (NT) which are having so many criteria for becoming a **vulnerable** one, (**2**) least concern (LC) that includes only abundant species which experience least threats on their survivability, (**3**) **data deficient (DD)** that includes those species which are although recorded and studied well but more information pertaining to their biology and ecology are still required for their inclusion in the threatened conservation categories, and (**4**) **not evaluated** that deals with those species which have not yet been assessed against definite conservation criteria (BirdLife International 2001).

4.14.6.6 Critically Endangered Birds in India

4.14.6.6.1 Indian White-Backed Vulture (*Gyps bengalensis*)

This species is distinguished by blackish gray color of the body with the striking coloration of dark brown at the portion of neck, the base of which is covered with white feathers, dark silvery color of beaks, and visible white rum during flight. Once abundant around 30 years back, the population of this species underwent sharp decline mainly due to the consumption of a nonsteroidal anti-inflammatory drug (**NSAID**) diclofenac while scavenging on the dead carcasses of cows and buffalos which were earlier treated with this drug (Green et al. 2004).

4.14.6.6.2 Indian Long-Billed Vulture (*Gyps indicus*)

This is a large-sized (nearer to 4 feet) vulture species having distinct white neck ruff at the bottom/base of a proportionately long neck of brackish-gray color. This semi-

Fig. 4.32 (continued) (**I**) Asian pied starling (*Sturnus contra*)
(**J**) Green Backed tit (*Parus monticolus*)
(**K**) Black headed cuckoo shrike (*Coracina melanoptera*)
(**L**) Indian Mayna (*Acridotheres tristis*)
(**M**) Plain Prinia (*Prinia inornata*)
(**N**) Streak throated swallow (*Hirundo fluvicola*)
(**O**) White Rumped Munia (*Lonchura striata*)
(**P**) Wire-tailed swallow (*Hirundo smithii*)
(**Q**) Yellow belied prinia (*Prinia flaviventris*)
(**R**) Pale –billed Flower pecker (*Dicaeum concolor*)

Fig. 4.33 Some charismatic birds with aesthetic appeal from different riparian ecosystems of Indian subcontinent
(**A**) Asian paradise fly catcher (female) (*Terpsiphone paradisi)*
(**B**) Asian paradise fly catcher (male) (*Terpsiphone paradisi*)
(**C**) Koel (female) (*Eudynamys scolopacea*)
(**D**) Blue whistling thrush (*Myophonus caeruleus*)
(**E**) Kalij pheasant (*Lophura leucomelanos*)
(**F**) Plaintive cuckoo (*Cacomantis merulinus*)
(**G**) Tree pie (*Dendrocitta vagabunda*)
(**H**) Asian house martin (*Delichon dasypus*)
(**I**) White-capped redstart (*Chaimarrornis leucocephalus)*

endemic (found in India, Pakistan, and Sindhi Pradesh) bird was abundant in the Gangetic Plain of India until in the mid-1990s and now is occasionally seen due to the veterinary drug [(nonsteroidal anti-inflammatory drug (**NSAID**)] leading to sharp decline of the population.

4.14.6.6.3 Slender-Billed Vulture (*Gyps tenuirostris*)

This species is distinguished by its slender neck with jet black color, triangular head with sharp elongated bill, conspicuously large ear cannels, and jet black-colored claws on the comparatively long legs. Since the mid-**1990s**, the population suffered a massive decline due to the consumption of nonsteroidal anti-inflammatory veterinary drug and has become very rare in its occurrences even the foot hills of the Himalayas and Gangetic Plain, the erstwhile habitats of this threatened avifauna.

4.14.6.6.4 Red-Headed or King Vulture (*Sarcogyps calvus*)

This medium-sized (in between **2** and **3** feet) vulture species is characterized by black colored body with red colored neck, head, and legs. White patches are only seen at the breast and the upper part of legs at the time of flight. Once abundant mostly in the Himalayan foothills of Himachal Pradesh and northeastern Indian states and also in the states of Gujarat, Rajasthan, now they are very seldom encountered because of the sharp decline of population, mainly attributed by poisoning and habitat destruction.

4.14.6.6.5 **Great Indian Bustard** (*Ardeotis nigriceps*)

This largest flying bird (more than **4** feet) belonging to the order Otidiformes is characterized with a horizontal body rests on two long bare legs. It was once found in higher abundance in the plain lands of arid and semiarid plain lands of western India with some population in the states of erstwhile undivided Andhra Pradesh and Karnataka, but their population has been dwindled to only around **150** individuals restricted only on to the state of Rajasthan. Habitat destruction due to land-use changes and hunting is considered as the major threats against the existence of this avifauna. Bengal florican (*Houbaropsis bengalensis*): This large-sized bird (more than **2** feet) has distinguished features such as black upper parts (head, neck, breast); white wings with brown-bronze color bars on dorsal part, more visible during flight; and long legs. It was once found in good numbers in Himalayan foothills of the State of Himachal Pradesh and also in the grasslands of the valleys of Ganges and Brahmaputra in the states of West Bengal and Assam, respectively.

Fig. 4.34 Some gorgeous birds of prey (large) of Indian subcontinent
(**A**) Oriental Honey Buzzard (*Pernis ptilorhynchus*)
(**B**) Gray Headed Fish Eagle (*Ichthyophaga ichthyaetus*) or
(**C**) Eurasian Marsh Harrier (*Circus aeruginosus*)
(**D**) Black Kite (*Milvus migrans*)
(**E**) Common Peafowl (*Pavo cristatus*)
(**F**) Eurasian Sparrow hawk (*Accipiter nisus*)
(**G**) Brahminy Kite (*Haliastur indus*)
(**H**) Crested Serpent Eagle (*Spilornis cheela*)
(**I**) Himalayan Griffon Vulture (*Gyps himalayensis*)

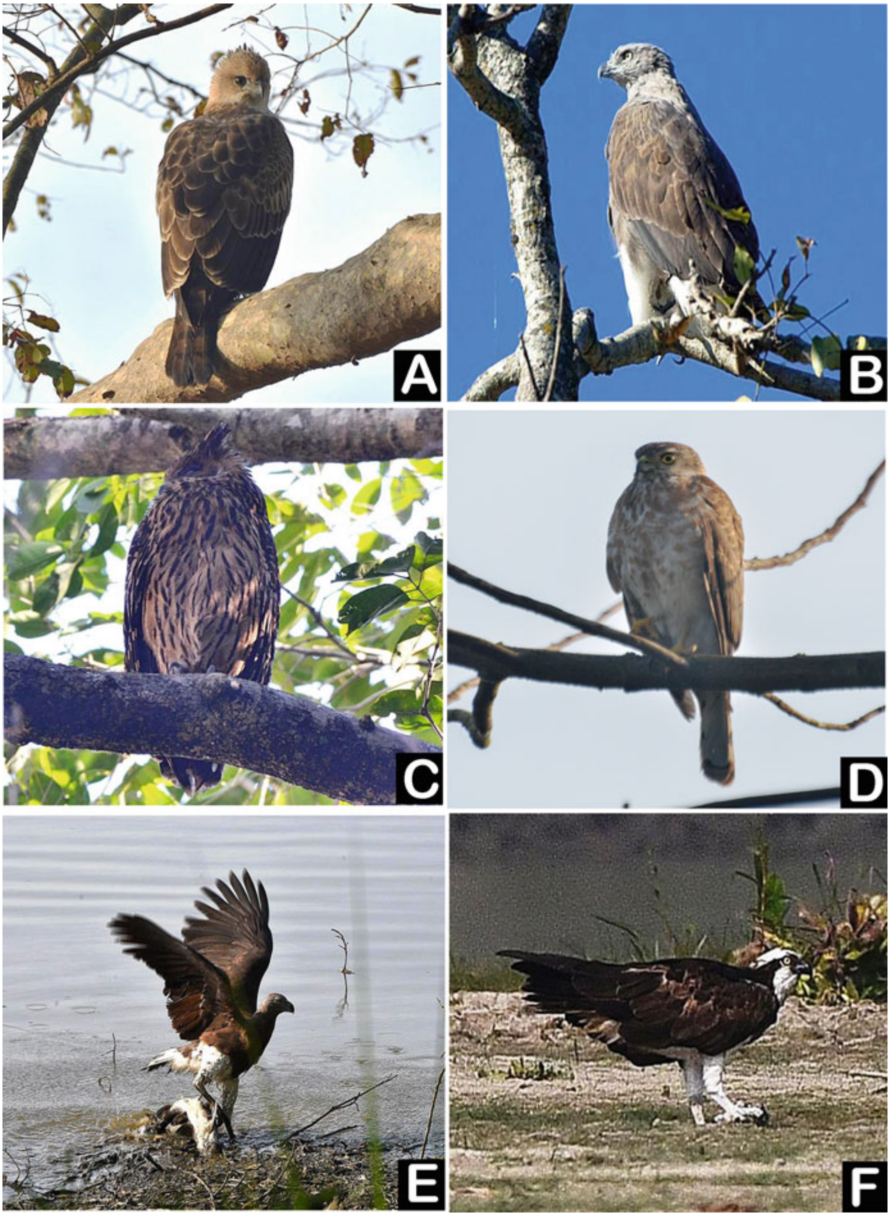

Fig. 4.35 Some more birds of prey of Indian subcontinent
(**A**) Changeable hawk eagle (*Spizaetus cirrbatus*)
(**B**) Grey Headed Fish Eagle (*Icthyophaga ichtyaetus*)
(**C**) Brown Fish Owl (*Ketupa zeylonensis*)
(**D**) Shikara (*Accipiter badius*)
(**E**) Grey Headed Fish Eagle (*Icthyophaga ichtyaetus*)
(**F**) Osprey (*Pandion haliaetus*)

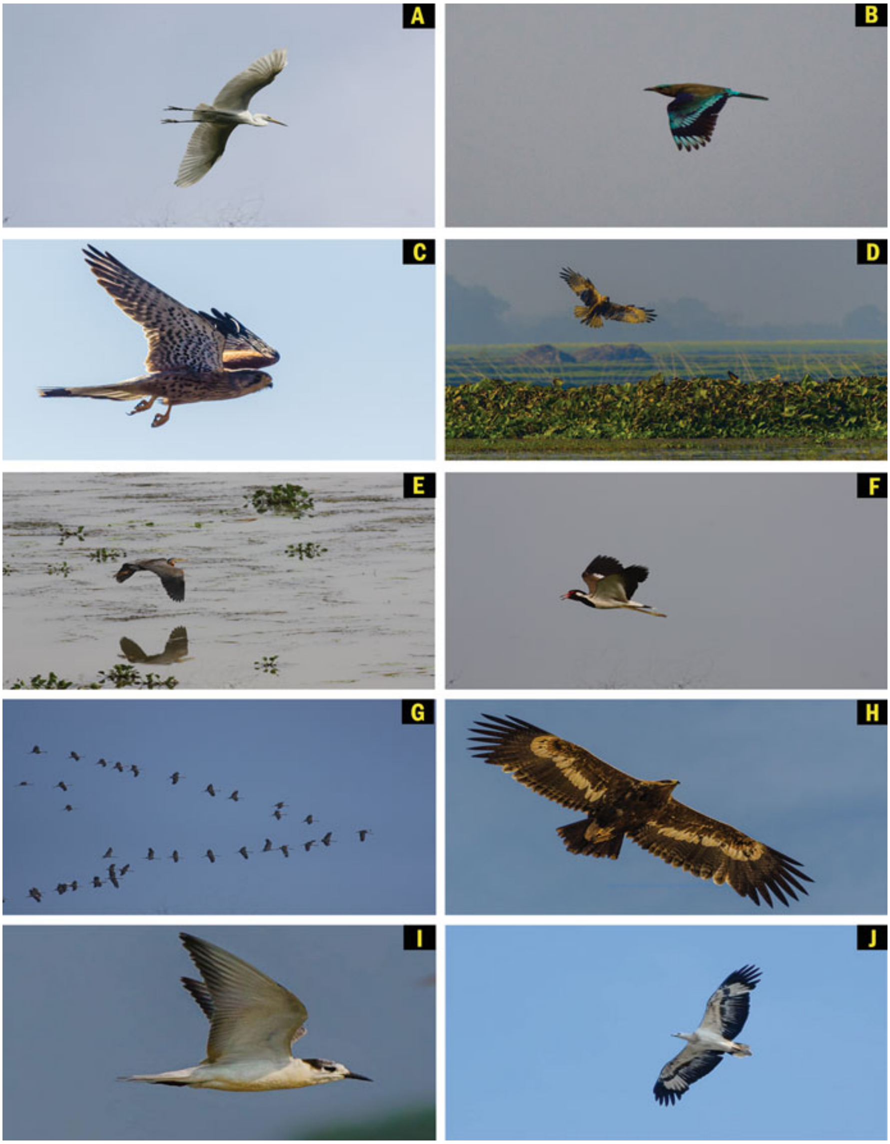

Fig. 4.36 Some birds on their wings, bridging the gap between terrestrial and aquatic ecosystems
(**A**) Large egret (*Casmerodius albus*)
(**B**) Indian roller (*Coracias benghalensis*)
(**C**) Common kestrel (*Falco tinnunculus*)
(**D**) Eurasian marsh harrier (*Circus aeruginosus*)
(**E**) Darter (*Anhinga rufa*)
(**F**) Red lapwing (*Vanellus indicus*)
(**G**) Flamingo (*Phoenicopterus roseus*)
(**H**) Crested serpent eagle (*Spilornis cheela*)
(**I**) Whiskered tern (*Chlidonias hybrida*)
(**J**) White-bellied sea eagle (*Haliaeetus leucogaster*)

4.14.6.6.6 Himalayan Quail or Mountain Quail (*Ophrysia superciliosa*)

This long-tailed quail with gray eyebrows, cheeks, and neck is endemic to India restricting its distribution in mountain ranges of Uttarakhand and Garhwal Himalayas. Habitat destruction mainly due to open cast mining has appeared to be major cause of their population decline.

4.14.6.6.7 Pink-Headed Duck (*Rhodonessa caryophyllacea*)

It is a large-sized duck (around 3 feet height) endowed with pink-colored tufted head, bill, and neck which are sharped in contrast to blackish throat. Once distributed in the Gangetic Plain, this species was last encountered around 70 years back and along with another critically endangered avian species, Himalayan quail, which is thought to become extinct from India.

4.14.6.6.8 White-Bellied Heron (*Ardea insignis*)

This species characterized by a long crest and white shiny vent, belly, and breast enjoys a very restricted distribution in the states of West Bengal and other north-eastern states.

4.14.6.6.9 Christmas Island Frigatebird (**Fregata andrewsi**)

This large sea bird distinguished by milkish white belly and silvery black dorsal side including two large expanded wings. Once it had wide range of distribution in the Indian Ocean and the Indo-Malaysian Archipelago.

4.14.6.6.10 Siberian Crane (*Grus leucogeranus*)

This largest (nearer to **5** feet) migratory bird of India is completely white in color except for black primaries and dark red mask near the eyes. Out of three populations (eastern, central, and western) categorized based on the location of the breeding grounds, the central population was considered to be extinct in India (last located during 2002). The same fate was with western population in Iran, but the eastern population with around **4000** species have been found to experience wintering in the Poyang Hu Lake in China. Hunting in its migratory routes, construction of dams, and mining of oil have been considered as the prime threats on the survivability of this avifauna.

4.14.6.6.11 Sociable Lapwing *(Vanellus gregarius)*

This small-sized (around **5** inches) and multicolored migratory aquatic birds are seen to move on the bank and over the macrophytes of littoral zones in the freshwater wetlands and can be identified by observing its brown crown on the head and round white-colored ring over the eyes in the forehead. Although it was seen migrating widely in different North Asian countries including India, it is only found in small numbers in the wetlands of Rajasthan and Gujrat, pointing out drastic decline of its population during last few decades without that much of established reasons.

4.14.6.6.12 Spoon-Billed Sandpiper *(Eurynorhynchus pygmeus)*

The breeding adult of this small-sized stint (maximum **6** inches) is distinguished by rufous orange-colored head and the presence of brown streaks over the neck and breast. Although this migratory species was occasionally encountered in the coastal area of West Bengal, it was only sighted for the last time from the Chilika Lake, of the State of Odisha in the year 1981 (Rahamani 2012).

4.14.6.6.13 Jerdon's Courser *(Rhinoptilus bitorquatus)*

This endemic, nocturnal, and small-sized courser (**9** inches) is distinguished by black stripes over the head, large elliptical eyes, grayish brown body color, and whitish throats and bellies. Although this bird was recorded around **100** years back from the Andhra Pradesh and Eastern Maharashtra, for a pretty long time, it was not sighted until the early **2000**s (Rahamani 2012). Around **200** individuals of this species are thought to have been existed in India which require serious conservation attention (Rahamani 2012).

4.14.6.6.14 Forest Owlet *(Heteroglaux blewitti)*

This small-sized owlet (maximum **10** inches) is endemic to India and is characterized by banded wings and tail on a dark gray-colored body. Habitat destruction (deforestation coupled with the changes of plants composition), predation pressure, changes in the land use, and poaching have been established as the prime factors leading to sharp decline of this species which usually prefer to inhabit in the open deciduous forest dominated by the teak plant (*Tectona grandis*).

4.15 Endangered Wild Flora and Fauna of India

Animals are not spread evenly and uniformly over the earth. Sometimes the fauna of one country is surprisingly similar to another, and sometimes it is markedly different. Existing beliefs center around two perceptions:

1. The nature created different forms of animals according to suitable habitats that are present in the various countries.
2. All animals of a kind have evolved from the same simple forms over thousands of millions of years of evolution. Climate has a great deal to do with the multiplication and distribution of various animals and plants on earth. Man has been exploiting the nature and its resources unlimitedly for his best possible life. Many wild species of plants and animals have become extinct, and many others are facing the danger due to overhunting and deforestation. According to the Red Data Book of the **IUCN** (International Union for Conservation of Nature and Natural Resources), about **245** species of animals (including **139** birds) have already become extinct and nearly **600** more species of animals and birds are leading towards extinction. This has a direct bearing on ecological balance, because many wild animals occupy a vital position in the functioning of natural ecosystem.

As many as **500** million kinds of plants, animals, and microorganisms have made this planet home since life began over **3.5** billion years ago. Today, there are only five million to ten million species alive, but it is difficult to know exactly how many species still exist, because there are many biologically uncharted areas such as the tropical rain forests where some estimate over **90%** of the living organisms remain unclassified. As species evolve, the old give way to the new. Many of the so-called extinct species are represented today by their descendants. Thus, many species did not die off as such but were simply altered during evolution. Other species vanished completely as a result of drastic climate changes or increasing environmental resistance created by excess predation or disease. The dinosaurs, for example, perished rather abruptly all over the world **65** million years ago, possibly as a result of global cooling.

Much more recently, at the end of the Pleistocene epoch **10,000** years ago, many large mammals such as the saber-toothed tiger and giant tree sloth vanished from North America. Their extinction resulted either from climatic changes at the end of Ice Age or possibly from Siberia. As these people moved south and east, they hunted the large mammals such as the wooly mammoth, wooly rhinoceros, giant deer, ground sloth, mastodons, giant beavers, saber-toothed tigers, bison, and elk. They undoubtedly also competed for the same wild animals for food resources.

One vertebrate species is becoming extinct every **9** months, compared with a natural rate of one species every thousand years. On adding the plants, insects, and microbes in this respect, the rate may be as high as one species per day. Ecologists argue that plant extinctions will have much more profound impacts on the ecosystem and also will lead to the extinction of animals because plants from the base of the food web.

The ongoing assertion and speculation of the environmental researchers point out to the possibility of acceleration of the extinction rate which can reach to **20,000** species loss per year if the world's population continues to grow and nations continue to destroy wildlife habitat by expanding agriculture and other activities at the current pace. At the rate, **400,000** species of plants and animals could be wiped out in **20** years. World wildlife expert Norman Myers argues that we could lose **one** million species by the first decade of **2000**. Although such high rates of extinction are probably exaggerated, extinction will undoubtedly increase unless we make conscious efforts to curb population growth and properly manage our renewable and nonrenewable resources.

Animals, particularly large ones, seem in greater danger of extermination than to plants. Island animals, such as the flightless dodo of Mauritius (exterminated in 1693), are especially vulnerable. Similar efforts on a smaller scale, to protect such plants as wood orchids, trailing arbutus, and other wild flowers, have been needed in many parts of the country to insure continuation of the native flora. The establishment of national parks and of wilderness areas, where the ecological balance is left as free of human influences as possible, is larger endeavors. They are aimed at preventing the extinction of living things that are interesting to some people now and may be highly useful to others in years to come.

Some species of plants and animals have already become extinct, and there are many facing danger of extinction. The basic reasons of extinction of wildlife are as follows:

1. Destruction of their natural habitats due to expanding agriculture, urbanization, and industrialization
2. Overgrazing by domestic animals that convert the area into deserts
3. Poaching for meat, skin, fur, ivory, rhino horns, etc.
4. Export of some species

The Botanical Survey of India (**BSI**) could so far complete survey of plant resources in only about **3/5** of the country. As per the targets set, the BSI should have completed the survey of the remaining **2/5** of the country by 1998. It is planned to publish national flora of the country in **24** volumes by **2000** AD.

The Zoological Survey of India (**ZSI**) could so far survey only about **1/3** of the country and is planned to complete the survey of the **75%** of the remaining **2/3** area of the country the research findings of which are to be published subsequently in the coming decades.

Data regarding all endangered plant and animal species of the country are also not complete. It was set that data regarding all endangered plant species will be inventorized by **1992**, for which the **BSI** had been restructured. In its Annual Report (1987–1988), **D.O**. En. has reported to have published **Vol. I** of Red Data Book of Indian plants covering **235** species. **Red Data Book** of Indian Plants **Vol. II** containing about **200** rare and endangered species is completed and printed (**D.O.** En. Annual Report, **1988–89**).

According to the Red Data Book of the **IUCN** (International Union for Conservation of Nature and Natural Resources), more than **1000** creatures are threatened with extinction, some very soon, some within a decade or so. Among these, facing most immediate danger are all species of rhinoceros, particularly the Indian variety, the royal Bengal and Siberian tigers, the Mexican grizzly bear, the red wolf, the mountain gorilla, the Arabian oryx, and the Asiatic lion.

4.15.1 Indian Endangered Flora

In India, nearly **450** plant species have been identified as endangered, threatened, or rare. A list of some such species in different parts of the country is given below (this may not be a complete list).

4.15.2 Indian Endangered Fauna

Some of the animal species listed below have been identified as endangered ones. This may not be a complete list.

Mammals

Primates. About **12** out of **19** are endangered. The chief species are hoolock gibbon (the only ape in India), lion-tailed macaque, stump-tailed macaque, pigtailed macaque, Nilgiri langur, the capped, golden, and Phayre's leaf monkey.

Pholidota. The Chinese pangolin and the Indian pangolin.

Carnivora. About **28** out of **36** are endangered. These include mainly Indian wolf, jackal, red fox, Indian fox, wild dog, the Himalayan brown bear, sloth bear, red panda, ermine, ratel, Malabar civet, tiger civet, striped hyena, tiger, Indian lion, leopard, desert cat, lynx, caracal, jungle cat, leopard cat, Pallas' cat, golden cat, marbled cat and other cats, dugong.

Perissodactyla. Great Indian one-horned rhinoceros, smaller one-horned and Asiatic two-horned rhinoceros, Indian wild ass, Tibetan wild ass.

Artiodactyla. Andaman wild pig, Kashmir stag or hangul, swamp deer or barasingha, brow-antlered deer, alpine musk deer, forest musk deer, mouse deer, blackbuck or Indian antelope, chinkara or Indian gazelle, chiru or Tibetan antelope, four-horned antelope or chousingha, gaur or Indian bison, wild yak, wild buffalo, tahrs.

Lagomorpha. Assam rabbit.

Rodentia. Eleven species of flying squirrels and two of marmots.

Cetacea. Gangetic dolphin, baleen whales, and other whales and marine dolphins.

Birds. These include geese, swans, pink-headed duck, white-winged wood duck, gray teal whooper swan, mute swan.

Indian black-crested baza; Blyth’s baza; black eagle; many hawks; eagles and falcons; game birds; bamboo partridge; red spurfowl; painted spurfowl; mountain quail; blood pheasant; satyr tragopan; Blyth’s tragopan; several pheasants such as koklass pheasant, chir pheasant, and peacock pheasant; Indian peafowl; several cranes like eastern common crane, black-necked crane, hooded crane, and great white crane; masked finfoot; several bustards and floricans like little bustard, houbara bustard, and the great Indian bustard; the Bengal florican, Indian skimmer; the Nicobar pigeon; several frogmouths particularly Hodgson’s frogmouth; the hornbills as white-throated brown hornbill, the rufous-necked hornbill, the great pied hornbill, the Indian pied hornbill, and the Malabar pied hornbill.

Reptiles: Several turtle, tortoise, and terrapin as leatherback or trunk turtle, the green sea turtle, the loggerhead and the hawksbill or tortoise shell turtle, the estuarine crocodile, the marsh crocodile and the gharial, monitor lizards, Indian python, Indian egg-eating snake.

Amphibia: The viviparous toad, Indian salamander.

Invertebrates: The coconut or robber crab (a large hermit crab); and insecta (dragonflies, butterflies and moths and beetles) have become, most endangered due to ongoing ecological perturbations.

4.16 Wildlife vs Endemism

Endemism, being an evolutionary concept focuses on the confinement of a species in a particular eco-region evoled through the distint evolutionary process after being triggered by the phenomenon of isolation. Such isolation eco-region can be geographical after being as noticed in the islands or the fragmentation of landscape forcing the organisms to stay apart by creating physical barriers (mountains or big rivers) or ecological barriers where the specialized ecological niche resist intermixing with subpopulations residing in separated habitats or physiological barriers where non-synchronization of breeding seasons with the climatic conditions impairs reproductions within populations. All of these have disrupted the flow and exchange of genes among the isolated populations which subsequently result in the evolution of endemic species. Despite the tremendous ability of movement from one part of the world to other remotely distant places, birds also experience endemism, like all other wild fauna.

India, as one of the **18**th megadiverse countries of the world, is unique in its species richness and diversity of wildlife. Many of the wildlife of this country historically have descended from various parent taxa originating in Gondwana. Volcanic eruptions and subsequent drastic climatic changes around **20** million years back had led to the extinction of many endemic Indian forms. Later many species immigrated to this country from other parts of Asia through two passes on either side of the emerging Himalayas. Endemism has appeared to be very high in this country. As endemic species have restricted themselves in small geographical range, they are more prone to the threat of extinction, and once lost, they like any other species can no way be recovered. Around **33%** of Indian plants belonging to **140** genera (Botanical Survey of India) are endemic. Again out of around **5150** endemic plant species, **4950** are angiosperms, and **200** are pteridophytes. High endemism has also been recorded for various faunal taxa, like insects, marine worms, centipedes, mayflies, and freshwater sponges found in this country. About **400** species of higher vertebrates found in this country are also endemic.

4.17 Wildlife Management in India

Owing to the continuous increase in the number of endangered species of flora and fauna, steps have been taken to protect and manage the wildlife of the country. Nongovernmental voluntary organizations and governmental organizations at state and central levels have been set up to protect the wildlife. Forestry and wildlife from an organizational view point have been primarily under control of state governments. However, quite recently the subject was given a top priority, and the Ministry of Environment, Forest and Climate Change has been entrusted with the task of environmental protection. The Department of Environment, Forests and Wildlife under this Ministry was set up with the view to ensure coordination between states and the center and speedy and faithful implementation of the steps to be taken in program of wildlife management in the country.

The wildlife management aims at (**i**) protection of natural habitats through controlled, limited exploitation of species, (**ii**) maintenance of the viable number of species in protected areas (national park, sanctuary, biosphere reserve, etc.), (**iii**) establishment of biosphere reserves for plants and animal species, and (**iv**) protection through legislation. Wildlife can also be preserved by (**i**) improving the existing protected areas as sanctuaries, national parks, etc., (**ii**) imposing restrictions on export of rare plant and animal species and their products, and (**iii**) educating public for environmental protection at all levels of education.

4.17.1 Classical Idea About Wildlife Conservation and Its Changing Trends

Conservation of domesticated varieties and conservation of wild population (including wild relatives) are two obligatory dimensions of biodiversity conservation in modern era. Thus conservation program for wild biodiversity must include the entire set of wild organisms for conservation and restoration as a consequence of India's Biodiversity Act (2002) which was introduced along with other national and international conservation-related laws by the National Biodiversity Authority, 2002. Throughout the world, human being radically affects the natural environment and the wildlife they contain.

They alter the habitats and change the species composition of flora and fauna which provide benefits to themselves (Dyke 2008). In India, from the beginning of the last century, a drastic decline in the populations of most of the large charismatic wildlife due to overhunting and habitat destructions encouraged the need of their conservation (Rangarajan and Shahabuddin 2006). In one side, huge megavertebrates like tiger, elephants, rhinoceros, and crocodiles which were considered as game animals hunted for trophies (Mitra 2010; Rangarajan and Shahabuddin, 2006), and on the other side, rapid growth of human population and uncontrolled utilization of natural resources drastically shrinks their natural habitats (Barve et al. 2005; Murali et al. 1996). These multidimensional threats immensely enhanced the necessity of their conservation. Thus, various national and international efforts came in the forefront to conserve their populations and natural habitats along with several laws and regulations (Bawa et al. 2011). In fact, all the attention and efforts of the state and **NGOs** towards saving our valuable wildlife are mostly restricted to the species found in the forests and other nonhuman localities (Majumder et al., 2013: Kothari et al., 2000).

Classical idea of conservation revolves around the thought of isolating the wildlife and its habitats from the direct contact of human activities (Sinha 2014; Bawa et al. 2011). Many such exclusionary conservationists believe strongly that conservation of wildlife within the protected areas is the one and only way as the wildlife have their home and are left on their own without any human interference there. They argue that if people are not secluded from the natural protected habitats, such area will perish affecting both human race and wildlife (Shahabuddin 2010; Sabrewal and Rangarajan, 2003).

This view was reflected when the **IUCN** followed those wildlife activists and included Royal Bengal tiger (*Panthera tigris tigris*) in its endangered (**EN**) category in 1969.This led to the development of **Wildlife Protection Act of 1972**, which primarily focuses on the conservation of those abovementioned large charismatic vertebrates isolated from human interference within the protected areas (Shahabuddin 2010, Rangarajan and Shahabuddin 2006, Gadgil and Guha, 1972). Accordingly, important forest and wetland areas were declared as national parks, sanctuaries, and special reserves for tigers, elephants, water birds, etc. These areas had been mostly the hunting reserves of indigenous royals or British elites where overhunting reduced the populations of erstwhile trophy animals to worrying states.

4.18 Wildlife Conservation: Animals Versus Humans?

Amid the continuing ecological decline of the Indian subcontinent, the massive network of parks and sanctuaries constructed after **1947** apparently stands out as a magnificent exception. The British, as proponents of shikar on a large scale, had very little interest in wildlife conservation. The consequences of record-breaking shikar sprees and habitat destruction were apparent by the time India gained independence. The tiger population, estimated at **40,000** at the turn of the century, had slumped to **3000.** The cheetah was extinct in **1952**. Other large mammals, such as the elephant and rhino, had disappeared from areas in which they were formerly quite numerous, while the Asiatic lion survived only in the Gir Forest.

The initiative for wildlife preservation came from the erstwhile princes, who had a rather better record than the British in maintaining their hunting preserves. The Indian Board for Wildlife was set up in **1952**; since then, a steady stream of parks and sanctuaries has been constituted. A major conservation effort, Project Tiger, was launched with the help of international agencies in **1973**, concerned exclusively with the protection and enhancement of tiger populations (more than **15** sanctuaries covering **25,000** km^2 come under this project).

National parks already cover **3%** of India's land surface, and there are proposals to double this area by the end of the century. In displacing villagers without proper rehabilitation, prohibiting traditional hunting and gathering, and exposing villages on the periphery to the threat of crop damage, cattle lifting, and manslaughter, the parks are, as they stand, inimical to the interests of the poorer sections of agrarian society.

This is not to stay that the preservation of biological diversity is not important, only that it should follow different principles. For India, as in other parts of the Third World, national park management is heavily imprinted by the American experience. In particular, it has taken over two axioms of the western wilderness movement: that wilderness areas should be as large as possible and the belief that all human intervention is bad for the retention of diversity. These axioms have led to the constitution of massive sanctuaries, each covering thousands of square miles, and a total ban on human ingress in the "**core**" areas of national parks (See Guha, Ramachandra 1989b).

These axioms of "**gigantism**" and "**hands-off nature**," though clocked in the jargon of science, are simply prejudices. When it is realized that the preservation of plant diversity is in many respects more important than the preservation of large mammals, a decentralized network of many small parks makes far more sense. The widespread network of sacred groves in India traditionally fulfilled precisely those functions. Yet modern wilderness lovers and managers are in general averse to reviving that system: apart from rationalist objections, they are in principle opposed to local control, preferring a centralized system of park management. The belief in a total ban on human intervention is equally misguided. Studies show that in fact the highest levels of biological diversity are found in areas with some (though not excessive) intervention.

Here, villages were abruptly told that they must stop grazing cattle in the sanctuary, a right they had enjoyed for several decades. When they refused to agree, an altercation between them and officials culminated in firings and the death of several villagers. Ironically, scientific studies now suggest that grazing was not adversely affecting bird life in the sanctuary; on the contrary, it was essential for keeping down excessive growth of the paspalum grass, which otherwise choked the shallow marshes, rendering them unsuitable for the migratory species of waterfowl which are one of the sanctuary's main attractions (Vijayan 1987).

4.18.1 Nongovernmental Organizations

There are a number of nongovernment, voluntary, national, and international organizations actively dedicated to wildlife conservation. The principal organizations are:

1. **Bombay Natural History Society**: It was founded in **1883**, engaged in collection of information and specimens of fauna and flora of India, Burma, and Ceylon.
2. **Wildlife Preservation Society of India, Dehradun**: It was founded in 1958 with several objectives of wildlife management.
3. **World Wide Fund for Nature India**: The World Wildlife Fund, Indian National Appeal, was launched in India in **1969** at the time of the XIIth General Assembly of the International Union of Conservation of Nature and Natural Resources, held at New Delhi. **WWF-**International was formed in **1961**, with its headquarters at Glands, Switzerland, and controlled by a Board of International Trustees. It has set up national appeals in several countries. The **WWF** in India was founded with a board of eight trustees and has its headquarters in Bombay. It has supported the well-known "**Project Tiger**" and other similar projects.

4.19 Aims of Wildlife Conservation

Indian wild fauna is very beautiful. In spite of rapid decline of forests, three exists as a rich variety of wild animals in different zones of the country. Their conservation has the following aims:

1. To protect and preserve the rare species of plants and animals from extinction
2. To preserve the breeding stock
3. To prevent deforestation
4. To maintain the balance of nature
5. To study the ecological relations of the plants and animals in natural habitat

4.20 Management and Conservation of Wildlife: National vs Global Perspectives

Man has not always foreseen the consequences of his selfish activities (killing of wild fauna and deforestation). But now the situation is becoming alarming, and we need to think over it. Man-made problem is to be solved by man himself, through proper ecological understanding of the biosphere. The whole biosphere is a workable ecosystem of which man is the important components as well as the factor. Present-day scientists as well as common people have started realizing the consequences of ecological imbalance which have necessitated the application of the basic principles of ecology in the conservation and management of nature and its resources.

Conservation is not only preservation or protection; rather it refers to scientific utilization of the natural resources by maintaining a sustained yield and also the quality of the resource. Conservation means taking care of our environment so that it may remain suitable for the biotic community including the human society. The development of such approach has necessitated to take up measures for the reduction of the adverse effects of overhunting, overfishing, felling trees, pollution, industrialization, etc.

Wildlife conservation requires the application of various ecological principles and an understanding of wildlife. The feeding habits of wild animals, their place in food chain, breeding behaviors, tolerance ranges, and the ecological requirements of individual species have to be understood for proper conservation and management. Old zone breeds of wild fauna will recycle themselves if given sufficient time. The conservation of the habitat alone can help conserve the wild flora and fauna. Two very important ecological programs have been launched on global level for the welfare of mankind and the biosphere. These are the International Biological Program (**IBM)** and the Man and the Biosphere Programme (**MAB**). Wildlife conservation is one of the objectives of the programs. The participating countries in the **IBM** and **MAB** have their own national committees. Besides these organizations, there are many other international organizations for financial and other assistance.

Main attempts to conserve and manage the wildlife population can be summed up as follows:

1. Establishment of special measures of protection and management to guarantee the perpetuation of wild species

2. Establishment of special measures to protect the endangered species
3. Extension and improvement of existing inventories
4. Maintenance of statistical data of wild lives
5. Study of various ecological aspects of the species being exploited commercially
6. National and international measures and agreements to control the exploitation rate so that exploitation should not exceed replacement rate (i.e., reproduction rate)
7. Preparation of guidelines for the management of species and their habitats

In India, many worth keeping steps have been taken for the management and conservation of wild flora and fauna. These measures are:

1. Formation of Wildlife Act. This act provides the protection of rare wild animals like lion, tiger, panther, elephant, python, gharial, predatory birds, etc. by imposing limits on hunting.
2. Establishing more amenity areas, e.g., nature reserves and national parks.
3. Species preservation schemes.
4. Assemblage protection.
5. Habitat improvement.
6. Preservation of breeding stock.
7. Artificial stocking.
8. Educating the common mass with the consequences of decline in wildlife.

Rivers, after having their origin mostly from the mountains flow down their slopes, gathering water from their tributary streams as they go, and then continue down to the plains till the point of confluence with the sea.

Rivers flowing from the two continents brought down layer upon layer of sediments, and as the ammonites died, their shells fell to the bottom of the sea and were covered by fresh deposits of mud and sand. But the sea is becoming narrower and narrower for year after year and century after century, and India was moving closer to Asia. As it neared, the sediments of the seafloor began to ruck and crumple so that the sea became increasingly shallow. But still the continent of India is advanced. The sediments, now compacted into sandstones, limestones, and mudstones, rose to form hills. Their elevation was infinitesimally slow. Nonetheless, some of the rivers that had been flowing south from Asia were unable to maintain their course over the slopes that were rising in front of them. Their waters were diverted eastwards and avoided the infant Himalayas by running round their eastern end, eventually joining the Brahmaputra. This transformation of sea into land began some **25** million years ago. It was, after all, some **600** million years ago that simple animals began to swim in the ancient seas and over **200** million years since amphibians and reptiles invaded the land. Birds developed feathers and wings and took to the air a few million years afterwards, and mammals evolved fur and warm blood around the same time. Sixty-five million years ago, the reptiles fell into their still mysterious decline, and mammals assumed the dominance of the land which they still hold today. So **25** million years ago, as the island continent of India approached Asia, all the existing major groups of animals and plants, and indeed almost all the large families within those groups, got the chance of settlements and flourishing.

4.21 Causes of Wildlife Depletion: Identified Threats on Wildlife

Across the globe, human populations, pollution, temperatures, and introductions of exotic (non-native) species are generally on the rise. Meanwhile, wildlife habitats and water supplies are waning. These trends echo through many wildlife populations (mammals, birds, reptiles, and amphibians) signaling disturbing global changes. The major threats are as follows:

4.21.1 Habitat Destruction and Alteration

Most wild higher chordates depend on both aquatic and terrestrial habitats to complete their life cycle. The forest vegetation, tall grasses, margins of rivers, uneven ground, etc. are used as cover or shelter by the wild animals. Conservation of these habitats at local population and landscape levels is critical to maintaining viable populations and regional diversity of wildlife. All those environmental changes are expected to be the primary cause of the decline of the biodiversity resources. Major land-use practices affecting wildlife habitats include agriculture, silviculture, industry, and urban development. These practices are often associated with the filling and draining of wetlands that serve as the foraging grounds and breeding sites, migratory routes, or alteration of the hydrodynamics of stream and river ecosystems that affect natural functioning and the ability of the ecosystems to support viable populations. This reduces the freedom of movement of the wild animals to a large extent. Animals like deer, bison, tiger, rhino, etc. are unable to maintain their numbers when confined to relatively small areas. In order to get more timber, charcoal, and firewood, man has cut and destroyed many wild plants which form the main food of these animals. Food is one of the major factors of the habitat which controls distribution and numbers of wild animals. The absence of the chief food may even end in ultimate depletion and extinction of some wild animals.

4.21.2 Perturbation of the Environment: Threatening Effects on Biodiversity

Although a number of factors and environmental processes have been identified such as eutrophication, nondegradable wastes, nonjudicious utilization of natural resources, etc., global warming and chemicalization of the environment are more pronounced. The rivers and streams that run through the forests and plains contain untreated effluents of many factories, which make the river waters unsafe for drinking and may even act as killing agents. Drinking polluted water exposes them to disease. During the recent past, there had been a sudden decline in the number of wild animals. The hunting leopard or cheetah is now extinct. The one-horned rhinoceros has survived because of the protective steps taken by the government. The sanctuary of Gir Forest has saved the lions from extinction. The great Indian bustard is now facing extinction. Many ducks have become extinct in recent years.

4.21.3 Global Climate Changes

Global climate change is caused by the accumulation of greenhouse gases, and reductions of the ozone layer are now being linked to species declines. This raises serious questions about the future of wildlife in areas of high vulnerability, particularly species with specialized habitat requirements. The increase in frequency and severity of El Niño–Southern Oscillation events is likely associated with wildlife declines and has been closely related to negative effects on diverse fauna worldwide.

4.21.4 Chemical Contamination

Many wild animals encounter chemical contamination in both terrestrial and aquatic environments. Chemicals applied to agricultural fields, and forests may directly expose terrestrial juveniles and adults to harmful levels of herbicides, insecticides, and fertilizers. Furthermore, because aquatic environments are the ultimate sink for most chemical contaminants regardless of their source (e.g., agriculture or industry), all aquatic stages of amphibians are likely exposed.

4.21.5 Disease and Pathogens

Some amphibian mass mortality events reported in relatively pristine areas of the world have now been linked to infectious diseases. This suggests that pathogens are responsible for declines of some species. Two primary pathogens that appear to be involved are now the current focus of attention: a parasitic chytrid fungus and *Iridovirus*. Pathogens have more attention for any significant to conservation issue because they can interact with other factors and likely have enhanced susceptibility of various species or populations to other threats.

4.21.6 Commercial Exploitation

Hunting and poaching offer good prospects in earning more income with little efforts especially in a developing country. The prices of animal products are always spiraling. A good tiger skin is worth **3000–5000** rupees. Similarly, the tusks of elephants and the skin of other big cats are also costly. The horns of rhinoceros carry fancy price. This has led to the unlimited slaughter of these animals. Many big snakes are now reduced in number due to the export of skins. The meat of many animals like deer, wild boar, and nilgai has always been in great demand, attracting many professional hunters. The commercial trade in amphibians is a great concern for natural populations and communities for several reasons. **First,** the direct impact of commercial or illegal collection may remove a large portion of breeding adults and reduce the capacity of populations to sustain themselves. **Second,** the reintroduction of wild-collected or captive-reared amphibians (intentionally or accidentally) into natural populations may expose native animals to diseases or pathogens not present in the region (fish fungus). The protection of wildlife is a state subject, and many state governments are unable to protect the wildlife by suitable laws.

4.22 Potential Solutions for Wildlife Protection and Management

Wildlife helps in promoting economic activities that bring money through tourism. It contributes towards maintenance of biodiversity. The colorful birds, animals, and other life-forms in the forests are important in maintaining the eco-balance. Disappearance of forests or its reduction in area will cause disappearance of wildlife. Thus, conservation of forests and wildlife go side by side. Establishment of national parks and wildlife sanctuaries helps conservation of wildlife. Many countries have through legislation banned killing of birds and other animals. In India, restrictions are imposed on killings of lions, tigers, deers, chital, great Indian bustard and peacocks, etc.

Interdisciplinary approaches that include social, political, and economic components have been necessary to solve conservation problems in other groups of organisms and must therefore be considered to help conserve wildlife. Further, looking beyond the local population or ecosystem level to regional or even global scales will be necessary for many of the threats that cross political or geographic boundaries.

Many solutions will necessitate international involvement of all stakeholders, including the inter-exchange of research information on education, health, economy, and environmental management. Finally, lessons from the past efforts to conserve different wildlife belonging to higher chordates such as birds, amphibians, etc. on in-depth studies of their unique physiological, morphological, behavioral, and ecological features are expected to generate and necessitate formulation of different and innovative solutions.

For the last four decades, the **Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES)** has been the largest and by some accounts the most successful international wildlife conservation agreement in the world. The treaty entered into force in Washington, DC, in 1975, in response to concerns that many species were becoming red because of international trade across the national borders, and by enacting proper international treaty, collaboration, and cooperation attempts have been made to ensure such trade guarantee should not be continued to not to threaten or endanger wildlife. Since the initial stage, more than **30,000** species of animals and plants have been listed on the appendices of the convention including the larger charismatic wildlife such as from tigers, elephants, mahogany, orchids, etc.

4.22.1 Achievement of CITES So Far Towards Wildlife Conservation

Since **CITES** came into force, the convention has banned international trade in rhino horn and helped to ensure that rhinos continue to survive in the wild. **CITES** also banned international trade of ivory in **1989** to impose restriction on illegal trade in ivory which caused considerable declines in the populations of elephants.

However, this ban got some success with closure of some running ivory markets, resulting to discouragement and decrease of poaching and also recovery of some populations. Other measures adopted by **CITES** have led to improvements in the management and regulation of trade in a myriad of other species such as sturgeon caviar, some species of sharks, seahorses, crocodiles, etc.

4.22.2 Protection Efforts for Endangered Species

4.22.2.1 Protected Areas as a Conservation Strategy

The concept of protected areas (**PAs**) has been enunciated with the major objective to ensure all-round protection to the wildlife to a maximum extent by developing suitable and conducive conditions for the foraging, breeding, and resting of the wildlife. This can be achieved by combating the loss of habitats, resisting any attempt of deforestation, sustaining ecological integrity with the forest, management and maintenance of the green biomass by proportionately developing new and restoring the existing wetlands, not allowing the introduction of exotic species, stopping the uses of synthetic materials, prohibiting any kind of poaching, etc.

The forests of India occupy around **25%** of the total land area, of which **one-fifth** have been designated as "**protected areas**," the number of which steadily increased after the enactment of the **Wildlife Protection Act in 1972**. Such protected areas have also been identified and earmarked as "**conservation reserve**" and "**community reserve**" in order to facilitate peoples' involvement in establishment and management of such protected areas.

So far a network of **7** natural world heritage sites (Declared by the UNESCO), **18** biosphere reserves, **103** national parks, **537** wildlife sanctuaries, **50** tiger reserves, **16** elephant reserves, **26** Ramsar wetlands, **131** marine protected areas (**25** in peninsular India and **106** in islands), important coastal and marine areas (**62** sites along the west coast and **44** sites along the east coast), **467** important bird areas (**IBA**), **67** "**conservation reserves**," and **26** "**community reserves**" occurs in India covering an area of **1,60,901.77 km^2** (**5%** of the total geographical area of the country) (Forest Survey of India, 2019; Ministry of Environment and Forests, 2019). The wildlife in India enjoys a special status in the global perspectives in respect of diversity, abundance, distribution patterns, morpho-structural excellences, unique behavioral manifestations, royal or majestic attitudes, and last but not the least their functional contribution towards protection and maintenance of the diversified forest biomes of the country.

However, all those wild biotic components of nature have been under tremendous stress during the last several centuries leading to striking decline of this precious gifts of the nature because of the so many anthropological activities such as population explosion, large-scale urbanization coupled with industrialization, anti-nature perception of human beings leading to unscrupulous hunting of the charismatic royal animals, different forms of wildlife crimes and trades, forbidden poaching, etc. River ecosystem along with its associated flood plain wetlands and riparian forests in the river basins supports an array of wildlife by providing heterogeneities in the habitats and also supplying nutrients (autochthonous and allochthonous) towards the growth and propagation of plants (trees, shrubs, herbs, climbers, algae, and microbial assemblages) advancing the scopes for the wild animals to get shelter which in turn through prey–predator interactive relationships ensure the subsistence of the diversity and ecosystem health of the riparian forests. Wildlife being an integral part of any ecosystem plays a vital role in maintaining ecological balance. In an ecosystem, the biotic and abiotic components interact through food chains, food webs, biogeochemical cycles, and positive and negative population regulation. Therefore, decline or extinction of any species results in a chain of events which adversely affect the fruitful survivability of other species leading to an abrupt modification of the food chain–food web dynamics of the ecosystem. This “protected area approach” as a part of the in situ conservation strategy has been used for the conservation of several large riverine wildlife in India, such as gharials (*Crocodylus palustris*) in the National Chambal Gharial sanctuary, in the state of Madhya Pradesh, India, since 1979 and dolphins in Vikramshila Gangetic Dolphin Sanctuary, Bhagalpur, in the state of Bihar, India, since 1990 and Upper Ganges to Narora, Ramsar site in the same state, since 2005. However, these protected areas cannot guard the species against the risks from pollution, flow alteration, and other anthropogenic impacts upstream and in the catchments beyond their boundaries.

4.22.2.2 Priority of Species for the Conservation

Among several species constituting a wildlife community, some species have some special roles to play for the sustenance of the entire ecosystem which in turn ensure the existence of all other species. These species are categorized as keystone, umbrella, and flagship species, each of which is described in accordance with the functional roles played by a particular species to an ecosystem. A keystone species is one whose presence contributes to the diversity and health of the ecosystem. For example, top predators (like tigers) keep the populations of prey (like deer) healthy by ensuring protection of the entire forest. An umbrella species is one, like the bear or a rhinoceros, that requires a large habitat, and their own survivability ensures the growth and proliferation of so many others the so-called non-charismatic species. Therefore, protection to umbrella species renders benefits to so many other species in getting their own protection. A flagship species is chosen because of its appeal to the public for demonstrating conservation issues. For example, conservation of the Gangetic dolphin (*Platanista gangetica*) ensures the protection of so many other aquatic species including fishes and birds. Some of the flagship species chosen by the World Wildlife Fund (**WWF**) to bring attention to important conservation issues around the world include the giant panda, elephants (both African and Asian), the great apes, rhinos, whales, and marine (sea) turtles.

4.23 Conservation of Wildlife as an Essential Agenda: Focusing on the Objective of Wildlife Conservation

Conservation of wildlife is chiefly concerned with protection, propagation, preservation, and judicial control on the population of rare species in plant and animals in their natural habitat. This can be achieved by the international exploitation of nature, keeping its biological, physical components intact as per as practicable.

Conservation is essential because it not only restores the natural components but also helps to maintain the ecological balance. Most of the plant cultivation and species add to the annual income of men as well as serve as food components Besides, such venture help maintaining the ecological balance by nutrients and water cycling, soil formation and preservation, combating of climate change, and controlling the plant resistance invasive species. The objectives of wildlife conservation are as follows:

1. To study the rare species of plants and animals
2. To study the interrelationships between plant and animal in their natural habitat
3. To preserve the breeding stock of wildlife
4. To prevent deforestation
5. To maintain the ecological balance

4.24 The Threatened Wildlife Resources and Implication on River Environment

India, being a land of too great a range of widely differing complexities of ethnic cultures, languages, and religions, is endowed with diverse wild flora and fauna in an array of striking ecosystems. There are about **500** species of different mammals, around **2000** species of birds, and several hundred species of reptiles and amphibians.

The populations of wildlife from different ecosystems in different parts of India in general and wildlife having direct and indirect dependences on river ecosystem in particular have declined sharply during the last few centuries because of the drastic reduction of forests and the steep increase in the human population with lot of changes in the land-use patterns. Some remnants of different forest types are still present with their aesthetic glory along with supporting the lives of an array of wild mammals, reptiles, birds, and plants, and such substantial biodiversity wealth which still can be enjoyed is astonishingly great. However, very firm and pro-wildlife activities have been increasing involving peoples representing the different strata of life. Now in India, so many national parks, biosphere reserves, and other protected areas have been developed which are not only promoting ecotourism but also help build awareness towards wildlife conservation.

References

Alfred, J.R.B., and N.V. Subba Rao. 1997. Biodiversity (fauna) in India: An overview. *ENVIS Newsletter* 4: 2–6.

Alfred, J.R.B., A.K. Das, and A.K. Sanyal. 1998. *Faunal diversity in India, A communicative volume in the 50th year of India's Independence*, 1–497. Zoological Survey of India.

Ali, S. 1993. *The book of Indian birds*, 1–187. B.N.H.s, Oxford University Press.

Ali, S., and S.D. Ripley. 1983. *Hand book of the birds of India and Pakistan*. New Delhi: Oxford University Press.

Anon, 1991. *Animal resource of India*. Calcutta: Zoological Survey of India.

Bawa, K., G. Joseph, and S. Setty. 2007. Poverty, biodiversity, and institutions in forest–agriculture ecotones in the Western Ghats and Eastern Himalaya ranges of India. *Agriculture, Ecosystems, and Environment* 121: 287–295.

Benton, T.G., D.M. Bryant, L. Cole, and H.P.Q. Crick. 2002. Linking agricultural practice to insect and bird populations: A historical study over three decades. *Journal of Applied Ecology* 39: 673–687.

Bird Life International. 2001. *Threatened birds of Asia: The bird life international red data book*. Cambridge: Bird Life International.

Brave, N., M.C. Kiran, G. Vanaraj, N.A. Aravind, D. Rao, R. Uma Shaanker, K.N. Ganeshaiah, and J.G. Poulsens. 2005. *Conservation Biology*: 122–130.

Carson, Rachel. 1962. *Silent spring*, 1–323. Houghton Miffin/Penguin Group.

Chetry, D., and R. Rekha Chetry. 2011. Hoolock gibbon conservation in India. *Gibbon Journal* 6: 7–12.

Chetry, D., R. Medhi, P. Bujarbarua, and P.C. Bhattacharjee. 2001. Mammals of gibbon Wildlife Sanctuary, Assam, India. *Tiger Paper* 28 (4): 29–32.

Chivers, D.J. 1984. Feeding and ranging in gibbons: A summary. In *The Lesses Apes: Evolutionary and behavioral biology*, ed. H. Preuschoft, D.J. Chivers, W.Y. Brockelman, and N. Creel, 267–281. Edinburgh: Edinburgh University Press.

———. 1998. Measuring food intake in wild animals: Primates. *Proceedings of the Nutrition Society* 57: 321–332.

———. 2001. The swinging singing Apes: Fighting for food and family in far-east forests. In *The Apes: challenges for the 21st century, conference proceedings*, 1–28. Brookfield: Chicago Zoological Society.

Corbet, Jim. 1990. *Jim Corbet: Jungle Lore*, 1–167. Oxford University Press.

Cubit, G., and G. Mountfort. 1985. *Wild India: The wildlife and scenery of India and Nepal*, 1–208. London: William Collins Sons and Co.Ltd.

Daniel, J.C. 2002. *The book of Indian reptiles and amphibians*, 1–238. B.N.H.S, Oxford University Press.

Debata, S., R.M. Panda, and S.K. Palita. 2020. Chiropteran diversity and the key determinants of their distribution in Eastern Ghats, India. *Biodiversity and Conservation* 28: 2385–2404.

Dutta, S.K. 1992. Amphibians of India: Updated species list with distribution record. *Hamadryad* 17: 1–13.

Dutta, S.K., M.V. Nair, P.P. Mohapatra, and A.K. Mahapatra. 2009. *Amphibians and reptiles of similipal biosphere reserve*, 1–174. Bhubaneswar: Regional Plant Resource Centre.

Ellerman, J.R., and T.C.S. Morrison-Scott. 1951. *Checklist of palaearctic and Indian mammals, 1758–1946*. London: Bulletin of the British Museum (Natural History), 810 pp.

FSI. 2017. *Report of forest survey of India*. Government of India.

Gadgil, M., and R. Guha. 1992. *This fissured land: An ecological history of India*. Delhi: Oxford University Press.

Gee, E.P. 1964. *The wildlife of India*, 1–214. London: Collins.

Geissmann, T., M. Grindley, F. Momberg, N. Lwin, and S. Moses. 2008. *Hoolock gibbon and biodiversity survey and training in southern Rakhine Yoma, Myanmar: Preliminary report*, 1–31. Yangon: Myanmar Primate Conservation Program, BANCA, FFI, PRCF and Yangon University.

Green, R.E., I. Newton, S. Shultz, A.A. Cunningham, M. Gilbert, D.J. Pain, and V. Prakash. 2004. Diclofenac poisoning as a cause of vulture population decline s across the Indian subcontinent. *Journal of Applied Ecology* 41: 793–800.

Grinnell, J. 1917. The niche-relationships of the California thrasher. *Auk* 34: 427–433.

Guha, Ramachandra. 1989. Radical American environmentalism and wilderness preservation : A third world critique. In *Environmental ethics*, vol. 11 (1), 71–83. Springer.
Hutchinson, G.E., 1957. A treatise on limnology. Wiley, New York, N.Y., 1:1015 pp.
Huxley, J., ed. 1973. *The atlas of world wild life*, 1–208. London: Mitchell Beazley Publishers.
IUCN, UNEP, and WWF. 1980. *World conservation strategy: Living resource conservation for sustainable development*. Gland: IUCN/UNEP/WWF.
IUCN. 2006. *IUCN red list of threatened species*. www.redlist.org
Karr, J.R., E.J. Sven, and F. Brian. 2008. *Ecological health indicators. Encyclopedia of ecology*, 1037–1041. Oxford: Academic.
Kazmierczak, K. 2000. *A field guide to the Birds of the Indian subcontinent*, 1–352. London: Bloomsbury Publishing.
Khan, M., and H. Monirul. 2008. *Protected areas of Bangladesh: A guide to wildlife*, 1–304. USAID.
King, W. 1981. *Endangered birds of the world. The ICBP bird red data book*. Washington, DC: Smithsonian Institution Press.
Kitchell, J.F., R.V. O'Neill, D. Webb, G. Gallepp, S.M. Bartell, J.F. Koonce, and B.S. Ausmus. 1979. Consumer regulation of nutrient cycling. *Bioscience* 29: 28–34.
Kothari, A., N. Pathak, and F. Vanta. 2000. *Where Community Care: Community based wildlife and ecosystem management in South Asia*, 1–222. International Institute for Environment and Development.
Li, T., Xulei Huang, Xiaohui Jiang, and Xingong Wang. 2018. Assessment of ecosystem health of the Yellow River with fish index of biotic integrity. *Hydrobiologia* 814: 31–43.
Majumder, J., R. Lodh, and B.K. Agarwala. 2013. Butterfly species richness and diversity in the Trishna Wild-Life Sanctuary in South Asia. *Journal of Insect Science* 13 (1).: Article 79:1–13.
Martin, B.P. 1987. *World birds*. London: Guinness Superlatives.
Menon, V. 2014. *Indian mammals, A field guide*, 1–528. Hachette India.
Molur, S., S. Walker, M.A. Islam, M. Miller, C. Srinivasulu, P.O. Nameer, B.A. Daniel, and L. Ravikumar. 2005. *Conservation of western hoolock gibbon (Hoolock hoolock hoolock) in India and Bangladesh*. Coimbatore: Zoo Outreach Organization/CBSG-South Asia, 36 pp.
Murali, K.S., R.U. Shaankar, U. Shankar, K.N. Ganeshaiah, and K.S. Bawa. 1996. Extraction of non-timber forest produce in the Forests of Biligiri Rangan Hills, India, 2: Impact of NTFP extraction on regeneration, population structure and species composition. *Economic Botany* 50: 252–269.
Naoroji, R. 2006. *Birds of prey of the Indian subcontinent*, 1–692. Om Books International.
NWAP. 2002. *National Wildlife Action Plan (2002-2016)*. New Delhi: Ministry of Environment and Forests, Government of India.
Pandit, A.K. 1991. Conservation of wildlife resources in the wetlands of Kashmir, India. *Journal of Environmental Management* 33: 143–154.
Parker, S.B. 1982. *Synopsis and classification of living organisms*. New York: Mc Graw Hill Book Co.
Prater, S.H. 1971. *The book of Indian mammals*. 3rd ed. Oxford: Oxford University Press.
Pratiher, S., and K. Deulti. 2011. Distribution and threats of amphibian species in West Midnapore, District, West Bengal, India. *Frog Legs* 17: 1–8.
Rahamani, A.R. 2012. *Threatened birds of India: Their conservation requirements*, 1–861. Bombay Natural History Society.
Rangarajan, M., and Sabrewal. 2006. Displacement and relocation from protected areas: Towards a biological and historical synthesis. 4 (3): 359–378.
Rangarajan, M., and G. Shahabuddin. 2006. Displacement and relocation from protected areas: Towards a biological and historical synthesis. *Conservation and Society*: 359–378.
Ripley, S.D. 1982. *A synopsis of birds of India and Pakistan*. 2nd ed. Bombay: OUP/BNHS.
Rod, and Ken Preston-Mafham. 1999. *Primates of the world*, 1–191. Cassell plc.

RRC. 1999. *Manual of river restoration techniques*. River Restoration Centre.
Sabrewal, and M. Rangarajan, eds. 2003. *Battles over nature: Science and the politics of conservation*. New Delhi: Permanent Black.
Schmitz, O.J. 2006. Predators have large effects on ecosystem properties by changing plant diversity, not plant biomass. *Ecology* 87: 1432–1437.
———. 2008. Herbivory from individuals to ecosystems. *Annual Review of Ecology and Systematics* 39: 133–152.
———. 2010. *Resolving ecosystem complexity*. Princeton: Princeton University Press.
Schram, H., and M. Eggleton. 2006. Applicability of the flood pulse concept in a temperate floodplain river ecosystem thermal and temporal components. *River Research and Applications* 22: 543–553.
Seegert, G. 2000. The development, use, and misuse of biocriteria with an emphasis on the index of biotic integrity. *Environmental Science and Policy* 3: 51–58.
Shahabuddin, G. 2010. *Conservation at the crossroads: Science, society and future of India's wildlife*. Ranikhet: Permanent Black.
Shearer, J.S., and C.R. Berry Jr. 2002. Index of biotic integrity utility for the fishery of the James River of the Dakotas. *Journal of Freshwater Ecology* 17 (4): 575–588.
Sinha, A., H. Hariharan, B.S. Adhikari, and R. Krishmurthy. 2019. Bird diversity along riverine areas in the Bhagirathi Valley, Uttarakhand, India. *Biodiversity Data* 7: e31588. pp. 1–30.
Southwick, C.H., M.A. Beg, and M.R. Siddiqi. 1965. Rhesus monkeys in North India. In *Primate behavior: Field studies of monkeys and apes*, ed. I. DeVore, 111–159. New York.
Srivastava, A. 1999. *Primates of Northeast India*. Bikaner: Megadiversity Press, 106 pp.
———. 2006. Conservation of threatened primates of Northeast India. *Primate Conservation* 20: 107–113.
Tikader, B.K. 1983. *Threatened animals of India*, 1–307. Zoological Survey of India.
Van Dyke, Fred. 2008. *Conservation biology: Foundations, concepts, applications*. Springer. ISBN: 978–14020- 6890 -4.
Vijayan, S., and B. Pati. 2002. Impact of changing cropping patterns on man-animal conflicts around Gir Protected area with specific reference to Talala Subdistrict, Gujrat, India. *Population and Environment* 23 (6): 541–559.
Walker, S., S. Molur, W.Y. Brockelman, J. Das, A. Islam, T. Geissmann, and P.-F. Fan. 2009. Western hoolock gibbon *Hoolock hoolock* (Harlan, 1831). In *Primates in peril: The world's 25 most endangered primates 2008–2010*, ed. R.A. Mittermeier, J. Wallis, A.B. Rylands, J.U. Ganzhorn, J.F. Oates, E.A. Williamson, E. Palacios, E.W. Heymann, M.C.M. Kierulff, Y. Long, J. Supriatna, C. Roos, S. Walker, L. Cortés-Ortiz, and C. Schwitzer, 62–64. Arlington: IUCN/SSC Primate Specialist Group (PSG), International Primatological Society (IPS), and Conservation International (CI).
Wilson, E.O. 1975. Some central problems of sociobiology. In *Biology and social life*, Social science information, vol. 14 (6), 5–18. Sage.
———. 1988. *Biodiversity*. Washington, DC: National Academy Press.
———. 1992. *The diversity of life*. Cambridge, MA: Belknap Press of Harvard University Press.
Wilson, D.S. 1997. Biological communities as functionally organized units. *Ecology* 78: 2018–2224.
Wilson, D.E., and D.M. Reeder. 1993. *Mammal species of the world*. 2nd ed. Washington, DC/ London: Smithsonian Institution Press.
Wilson, K.A., E.C. Underwood, S.A. Morrison, K.R. Klausmeyer, W.W. Murdoch, B. Reyers, G. Wardell-Johnson, P.A. Marquet, P.W. Rundel, M.F. McBride, R.L. Pressey, Bode, K.A. Wilson, E.C. Underwood, S.A. Morrison, K.R. Klausmeyer, W.W. Murdoch, B. Reyers, G. Wardell-Johnson, P.A. Marquet, P.W. Rundel, M.F. McBride, R.L. Pressey, M. Bode, J.M. Hoekstra, S. Andelman, M. Looker, C. Rondinini, P. Kareiva, M.R. Shaw, and H.P. Possingham. 2007. Conserving biodiversity efficiently: What to do, where and when. *PLoS Biology* 5: e223.

Winemiller, K.O. 2007. Interplay between scale, resolution, life history and food web properties. In *From energetics to ecosystems: The dynamics and structure of ecological systems*, ed. K. McCann, D. Noakes, and N. Rooney, 101–126. Dordrecht: Springer.

Zhu, D., and J.B. Chang. 2008. Annual variations of biotic integrity in the upper Yangtze River using an adapted index of biotic integrity (IBI). *Ecological Indicators* 8: 564–572.

Chapter 5
River Pollution and Perturbation: Perspectives and Processes

Abstract Most precious resource of the world is the freshwater (**3%** of the total water on this planet). Most of the inland water bodies of the world with their freshwater resources are under threats of both point and non-point pollution, making the supply of clean water all most impossible to human being alongside causing the depletion of valuable aquatic biodiversity wealth of the nature. Such alarming ecological onslaught on river ecosystem in general and the biodiversity of river system in particular have attracted worldwide governmental support, and the supports of the United Nations Environmental Programs (**UNEP**), the World Wildlife Fund (**WWF**) and the International Union for the Conservation of Nature (**IUCN**). Rivers representing much cherished natural landscape in this world, perform countless vital functions towards the benefits of both societal and ecosystem, which include different human purposes such as water consumption for drinking, health maintenance, sanitation, agricultural, navigational, industrial alongside serving different aesthetic, cultural, spiritual, and recreational fulfillment. Throughout the length and breadth of the world, human-induced alteration of the structure and function of freshwater riverine ecosystem leading to large-scale eco-degradation has resulted in sustained deterioration of river health. Such long-term continuous abuse has reduced the ability of a river and other associated natural aquatic subsystems such as flood plains, wetlands, swamps, streams etc. to deliver ecological services and natural bioproducts.

In view of the above, the present chapter starting with defining and elaborating the concepts of different terminologies pertaining to pollution of rivers has discussed on the causes and consequences of several mode of pollutions in the riverine flows in the global context citing examples of Indian perspectives. Besides, major threats on river system such as climate change, eutrophication, pollution from different agricultural wastes, etc. have been discussed citing suitable case studies. The ecological perturbations resulting from the effects of all such pollutions have also been taken care of in the context of a country, India having vast networks of freshwater rivers and their associates inland water bodies.

Keywords River ecosystem health · Eco-degradation vs pollution · Pollution vs. Contamination · Non-point and non-point sources of pollutants ·

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Persistent pollutants · Toxic organic chemicals (TOCs) · Global climate change · Eutrophication · Environmental perturbations · Groundwater pollution · Hydrogeological assessment of water pollution · Heavy metals in Subarnarekha river · West Bengal · India · Interlinking of Rivers (ILR) · Pollution from religious activities

5.1 River Ecosystem vs Pollution

Pollution of river is not a recent development but has been intensifying in respect of intensity and dimension during the last couple of centuries keeping pace with population explosions, unplanned urbanization coupled with industrialization, nonjudicious exploitation of resource bases, direct human intervention by way of construction of dams, barrages, hydroelectric power stations, etc. However, the pollution of rivers assumed its higher momentum at the time of the industrial revolution, in the Europe during the early nineteenth century. Since then, two prime causative factors were identified for the initiation and aggravation considered of water pollution problem: firstly the discharge of both non-point and point pollutants and secondly, the rapid pace of urbanization coupled with industrialization leading to shrinkage of wetlands.

Streams and rivers within their drainage basins are central to surface water ecosystems. The directional movement of water is a fundamental property of river ecosystems. The energy after being dissipated from the moving masses of water affects the geomorphology of rivers, along with its sedimentation patterns; water quality parameters; and growth, development, and diversity of organisms. Rivers constituting an insignificant amount (**0.001 or 0.1%**) of the land surface accommodates only **0.0001%** of the water of the Earths with in river channels. In spite of such low quantity, running waters are of enormous significance to humans.

Erosion moves large amount of dissolved land particulate matters from the land to the sea (Wetzel 2001). Most of the rivers in India are seasonal and the entry of pollutants into flowing streams or river set-off a progressive series of physical, chemical, and biological events leading to aggravate the intensity of pollution load in the downstream water. The latest report indicate that majority of the Indian rivers are polluted due to increasing industrialization, urbanization, population pressure, and other developmental activities in their catchment area. The nature of the polluted water bodies are thus governed by the quality and quantity of the polluting substance.

Domestic or industrial effluents may adversely affect lives of natural stream by direct toxic action or indirectly through quantitative alteration in the character of the river or the stream bed. Industrialization, urbanization, and increased population of India have modified environment beyond limits. The problem of environmental pollution is more severe in developing countries like India, because of limited economy and technological resources than the developed countries. The disposal of industrial wastes poses a serious problem at present due to their diverse composition such as acids, alkalis, metallic ions, phenols, cyanide, pesticides, and many other organic and inorganic substances, which have become a pervasive threat to the natural ecosystems. Impact of different environmental toxicants have toxic effects on

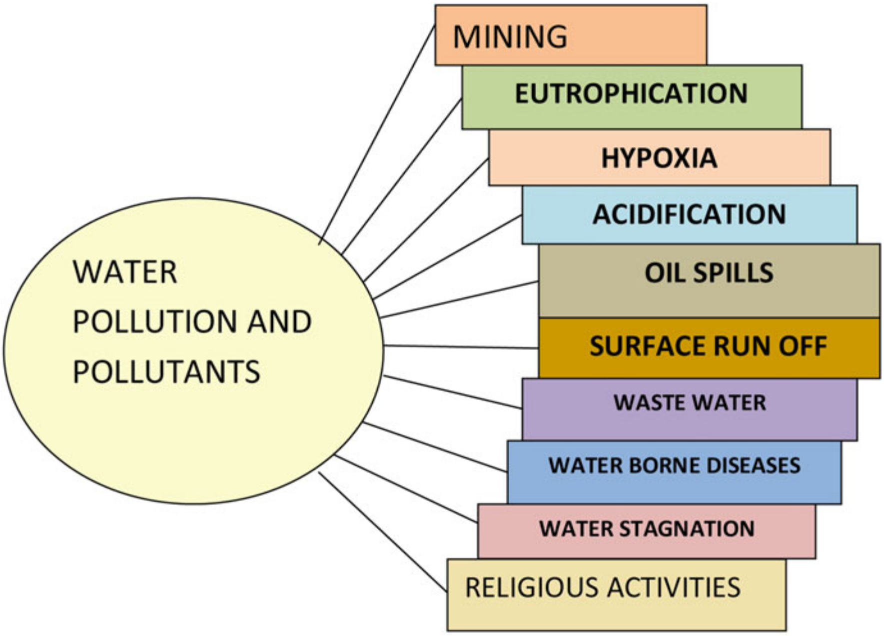

Fig. 5.1 Different types of water pollutions and sources of water pollutants

of organisms disturb and derail different biological processes at cellular, population, community and ecosystem levels of organizations (Barnett and Beisner (2007); Barnett et al. (2007); Barnett et al. (2008); Biswas and El-Habr (1993); Biswas (1972, 1975, 1978); Bond and Midgley (2000); Brown et al. (1998); Omerod (2004); Brown and Peet (2003); Brown et al. (2004); Chakraborty (2013); Chakraborty et al. (2013).

The problem of toxicants after being released from a multitude of sources, affect the aquatic ecosystems in complex pathways which demand the need for continuous monitoring and mitigating the effect. The study of the structure and functions of a biological community in the waste receiving water coupled with laboratory bio-assays studies for determining impacts of toxicants are required as a biological approach for pollution monitoring (Figs. 5.1, 5.2, 5.3, 5.4, 5.5, 5.6, 5.7, 5.8, 5.9, 5.10, 5.11, 5.12, 5.13, and 5.14, Tables 5.1, 5.2, and 5.3).

5.2 Definitions, Concepts, and Relationships with Similar Terminologies

5.2.1 Pollution

The term Pollution, although has become a password all over the world, is very difficult to define as each and every component of the environment is not only

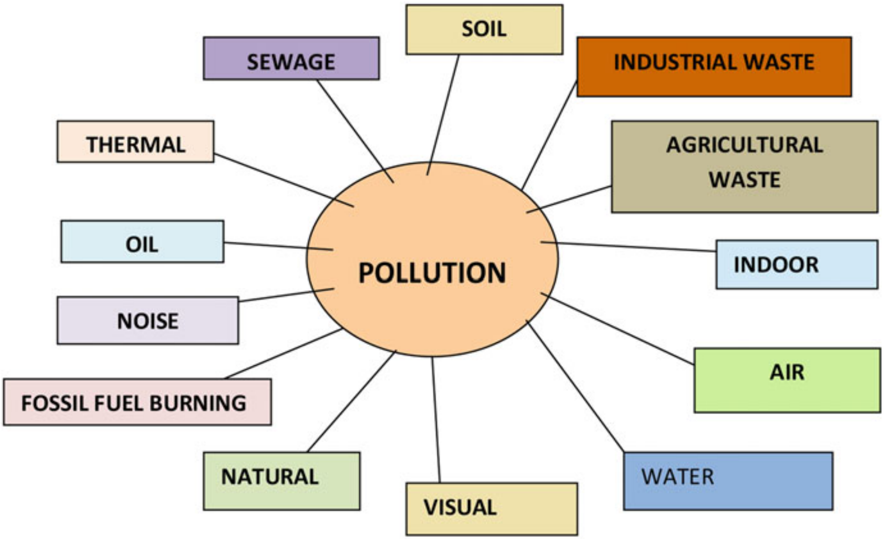

Fig. 5.2 Different categories of pollution in general

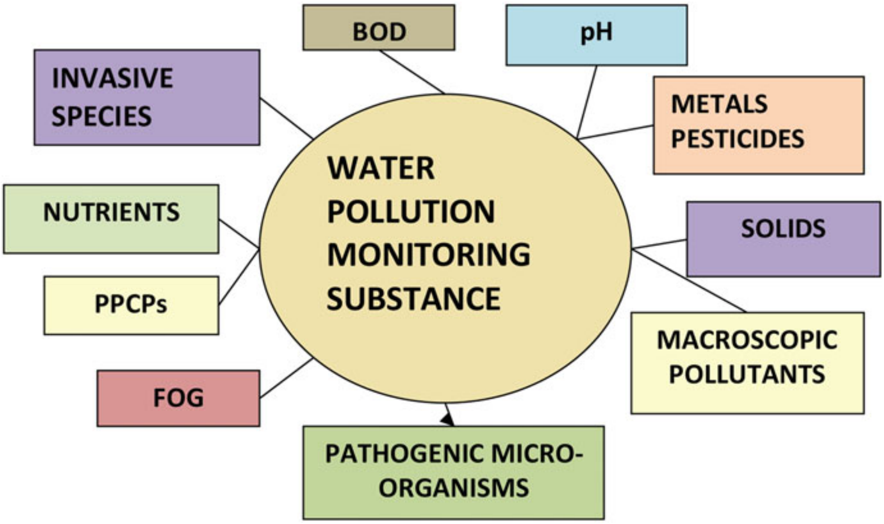

Fig. 5.3 Different factors and attributes for assessing water pollution

interlinked but interdependent with other elements, and so too are for pollution's effect. United States Environmental Protection Agency (**USEPA**) in the year 1989 defined pollution as "**The presence of matter or energy whose nature, location, or quantity produced undesirable changes and consequences in the ecosystem**

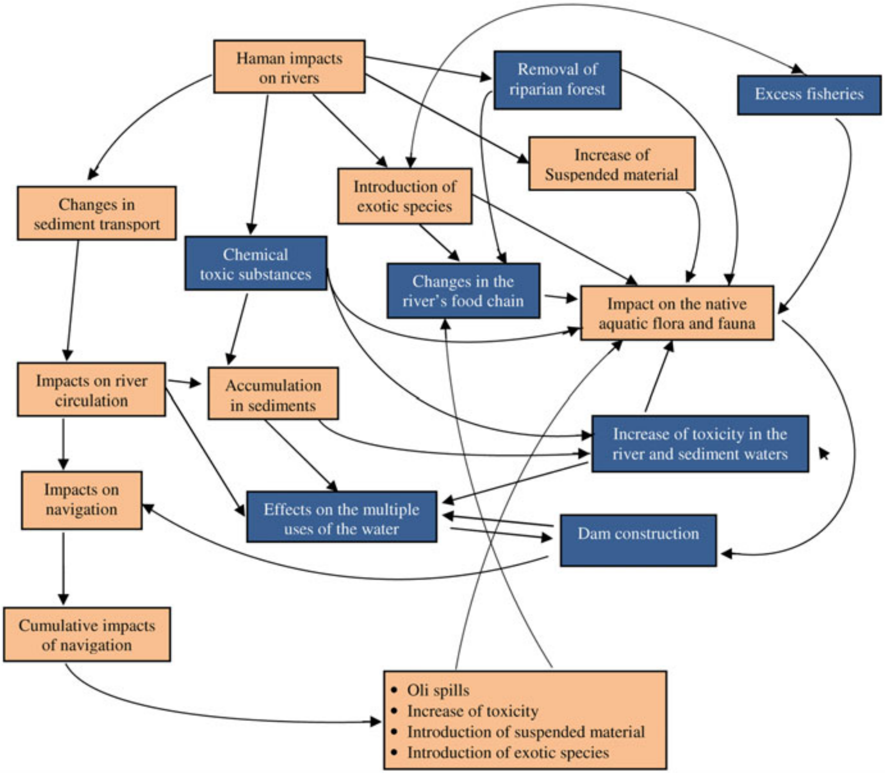

Fig. 5.4 Interlinkages among different contributors and receivers for causing aquatic pollution with their intricate pathways of interactions

functioning." Keller (1988) has defined as "**Pollution is for harmful substance that is present in the wrong place in the environment, in the wrong concentration, or at the wrong time, and as such it is damaging to living organisms or disrupts the normal functioning of the environment**."

Several other definitions which have been in use in the arena of environmental science over the years can be cited as "**Pollution is the impairment of the environmental quality by the addition of harmful impurities**." Water pollution is an undesirable change in the aquatic ecosystem because of the presence of unwanted substances in water beyond permissible limits for human health. The cause of pollution can be stated as the deleterious impact of derivatives of human production systems on human health or well-being. The most comprehensive definition of pollution has been given by E.P. Odum (1971) as "**The pollution is an undesirable changes in the physical, chemical and biological compartments of the environment partly or wholly due to human activities which directly or indirectly cause harms to human being along with the living world**."

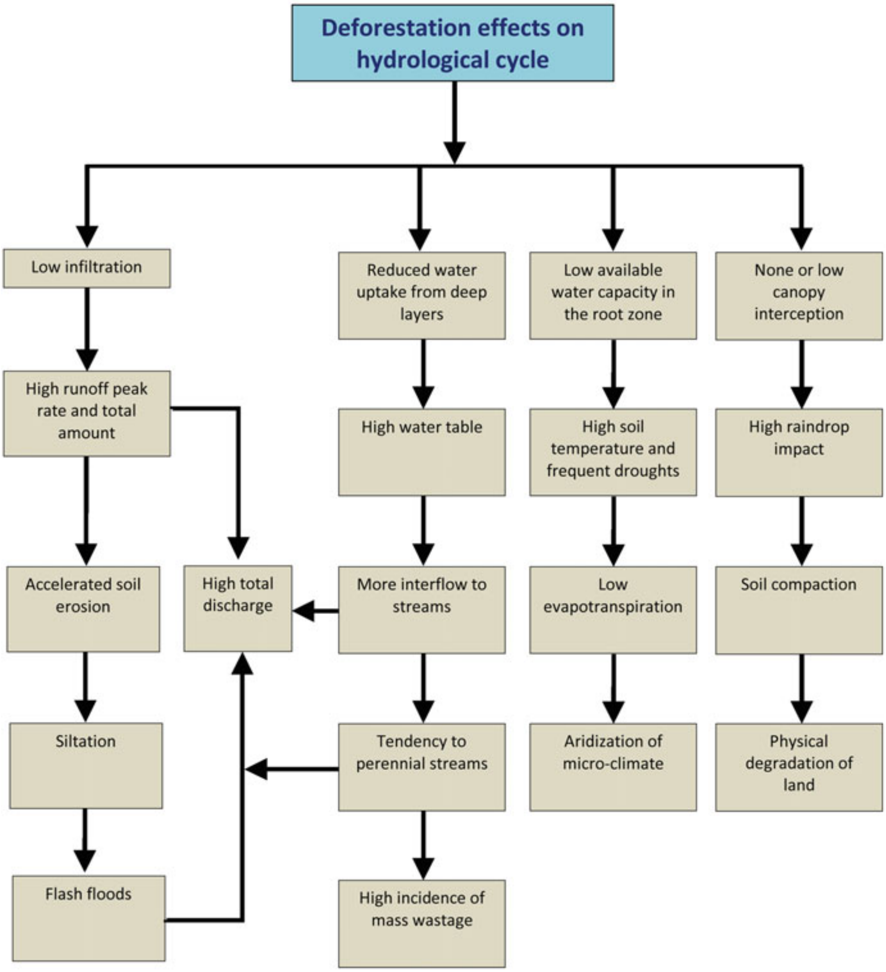

Fig. 5.5 Impact of deforestation on the hydrology and ecology of river ecosystem. Modified after Lal (1993)

5.2.2 *Relation Between Pollution and Eco-degradation*

Confusion still exists with regard to some more terminologies which appear to be synonymous with pollution such as eco-degradation which represents the deterioration of environmental qualities because of undesirable changes in the existing environmental setups, and therefore it can be inferred that if pollution is considered as cause, then eco-degradation is the result (Fig. 5.4).

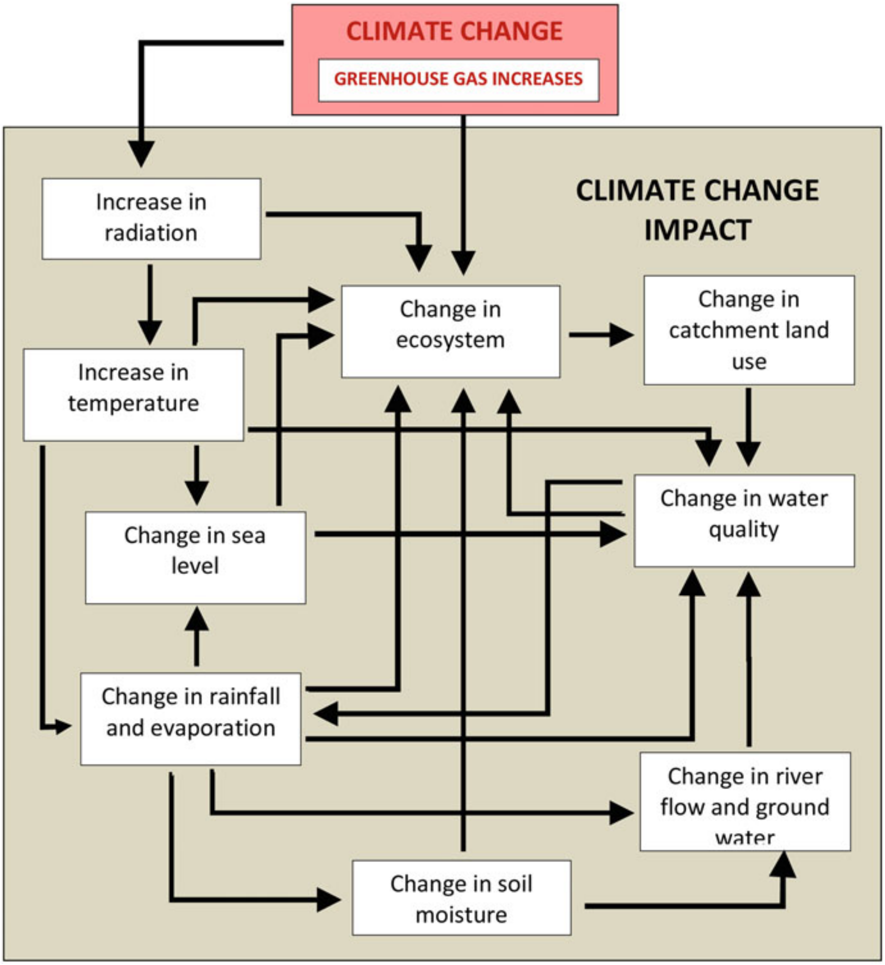

Fig. 5.6 Climate change and its impact on aquatic bodies in general and river ecosystem in particular

5.2.3 Pollution vs Contamination

Similarly the term contamination is very much like that of pollution. A contaminant is certainly a pollutant as it causes harm to the living world especially the human being, but it may or may not be present in the environment in the initial state; if it was there, its concentrations have gradually been increased to impose detrimental effects on the existing environment, both living and nonliving. On the other hand, the pollutants, the pollution causing substances are required by the living organisms in desirable quantities in normal concentration, the increase or decrease of which may lead them to achieve the status of pollutants. For example, heavy metals are required

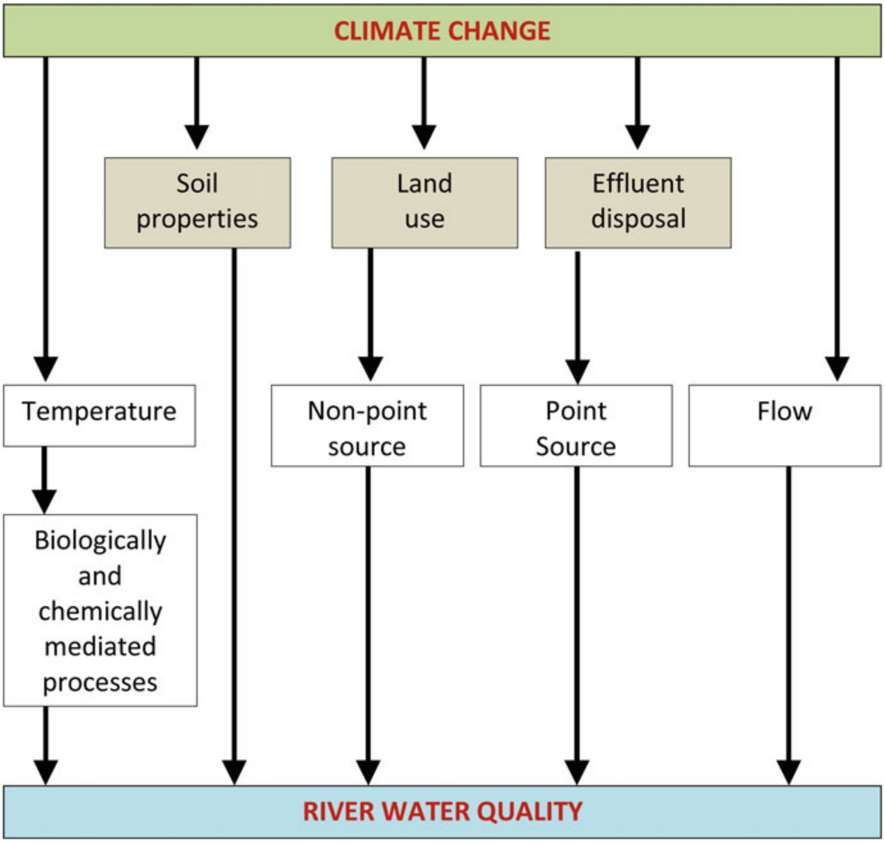

Fig. 5.7 Climate change and its effect on river water quality

by the human bodies in very minute or nano quantities as prosthetic groups for enzymatic functioning but certain increase of their quantities make them as pollutant as they invite lots of physiological disorders within the human bodies. Similarly, levels of **pH**, dissolved oxygen (**D.O**.), nutrients, turbidity, light, etc. representing major limiting ecological parameters in the water bodies if deviate from their normal permissible levels may cause undesirable changes in the functioning of the water bodies and thereby are designated as pollutants. These are in contrast to other ecological variables (temperature, biochemical oxygen demand (**B.O.D.**), conductivity, heavy metals, etc.) whose concentrations if are increased may lead to cause pollution. The major message which comes out from the discussion pertaining to pollution and its related terminologies is that the impacts of pollution are not restricted only to the target parts of the environment but will directly or indirectly affect other components of the environment as each and every components of earth are interlinked and interdependent.

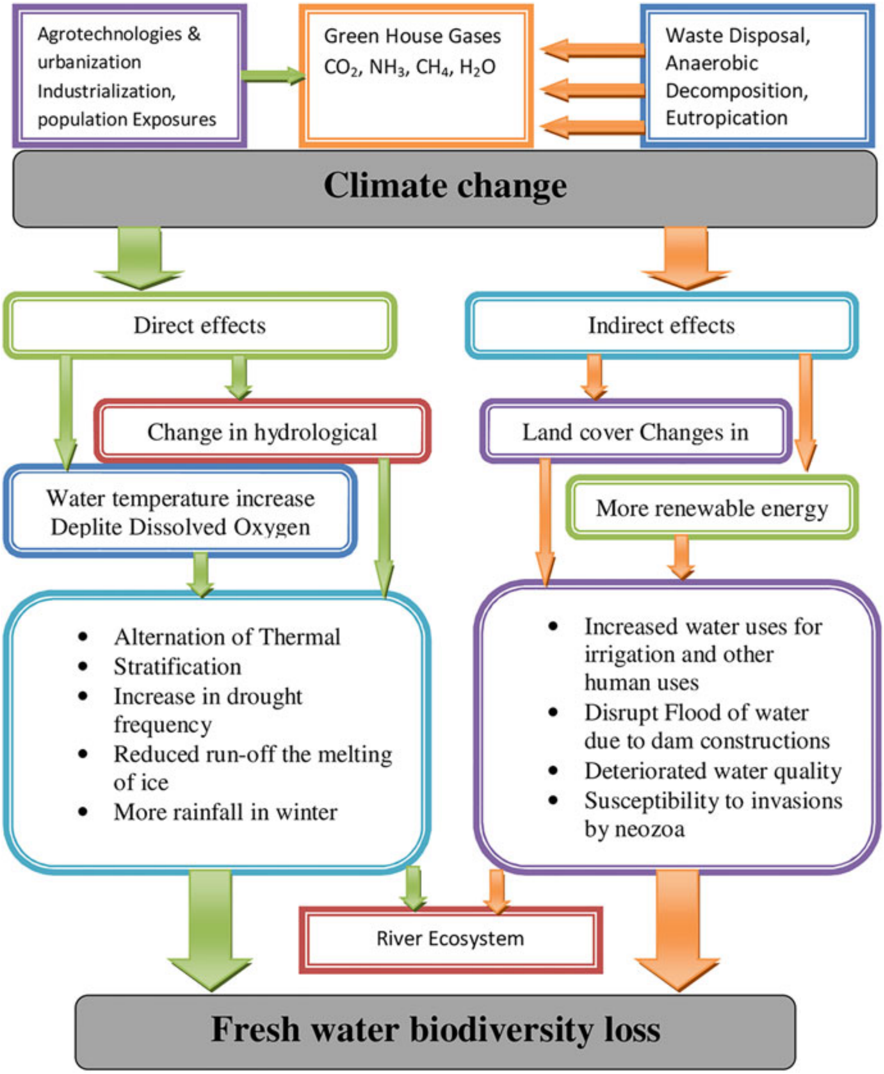

Fig. 5.8 Intricate processes of involved in the climate change mediated impact on freshwater river ecosystem

Pollution which initially affects one medium of the global environment moves into other media such as gaseous pollutants after being emitted from land and even from water reach to atmosphere and undergo several interactions with other components present there and form acid rains, lead to develop global warming, facilitate ozone layer destruction, cause the formation of photochemical smog, etc. and thereby impair the delicate ecological balance of vast sheet of surface water within sea, rivers, wetlands, etc. and groundwater under the earth.

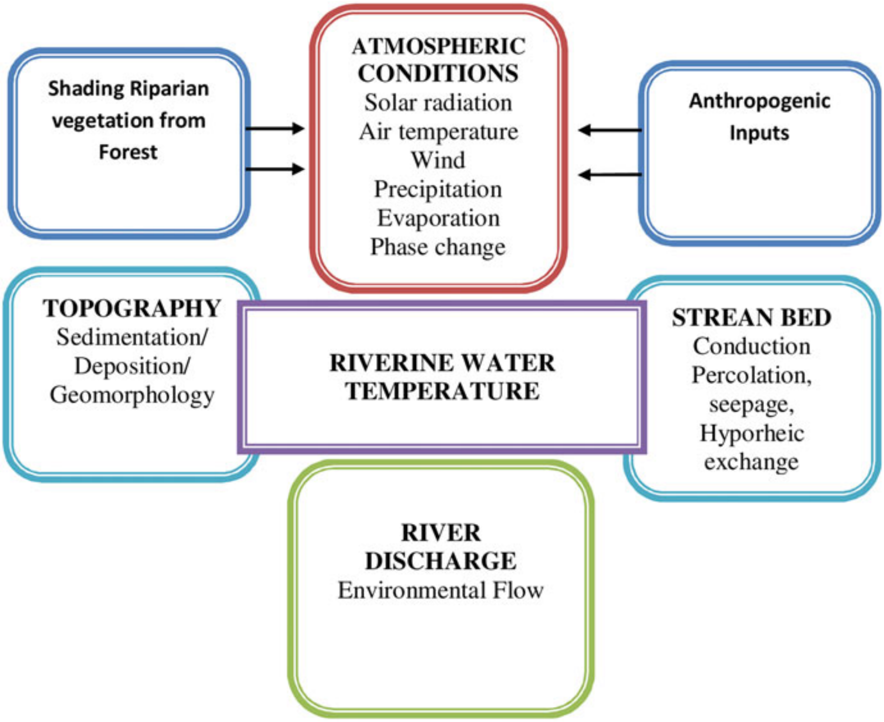

Fig. 5.9 The role of temperature, being a major limiting factor on river ecosystem

5.3 River Water Pollution

Water representing two-third of the earth's surface, mostly present as thin film on earth. **97%** of the water is salt water and rest **3%** is freshwater including the water which is being trapped as ice in the polar caps. Out of so many functions rendered by the water for the benefit of living world of the earth, it performs to maintain climate, dilute environmental pollution, and certainly support all forms of life. As far as surface freshwater pollution is concerned (Table 5.1), riverine pollution represents the major one, as human settlements have been evolved, developed, and continued flourishing along banks and within river basins of so many rivers of the world mainly because of three reasons:

1. Accessibility and abstraction of water for the purpose of drinking, agriculture, transport, and navigation
2. As the prime source for developing energy (hydropower plants)
3. For the establishment and growth of different industries.

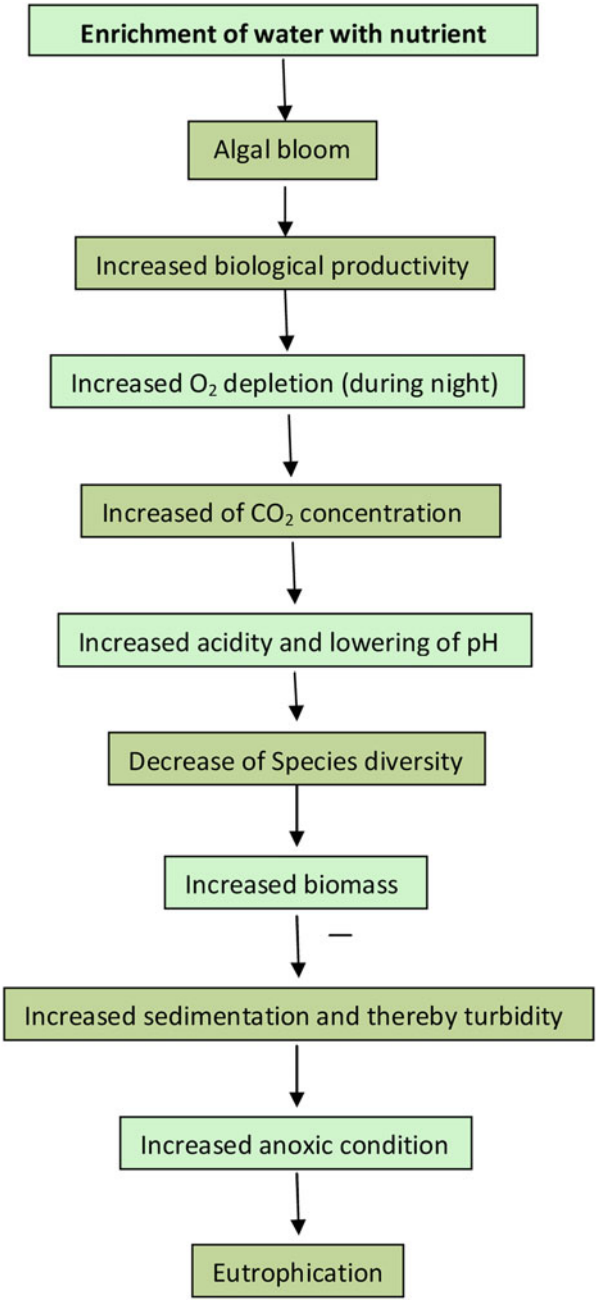

Fig. 5.10 Schematic representation of ecological changes because of eutrophication of aquatic ecosystem

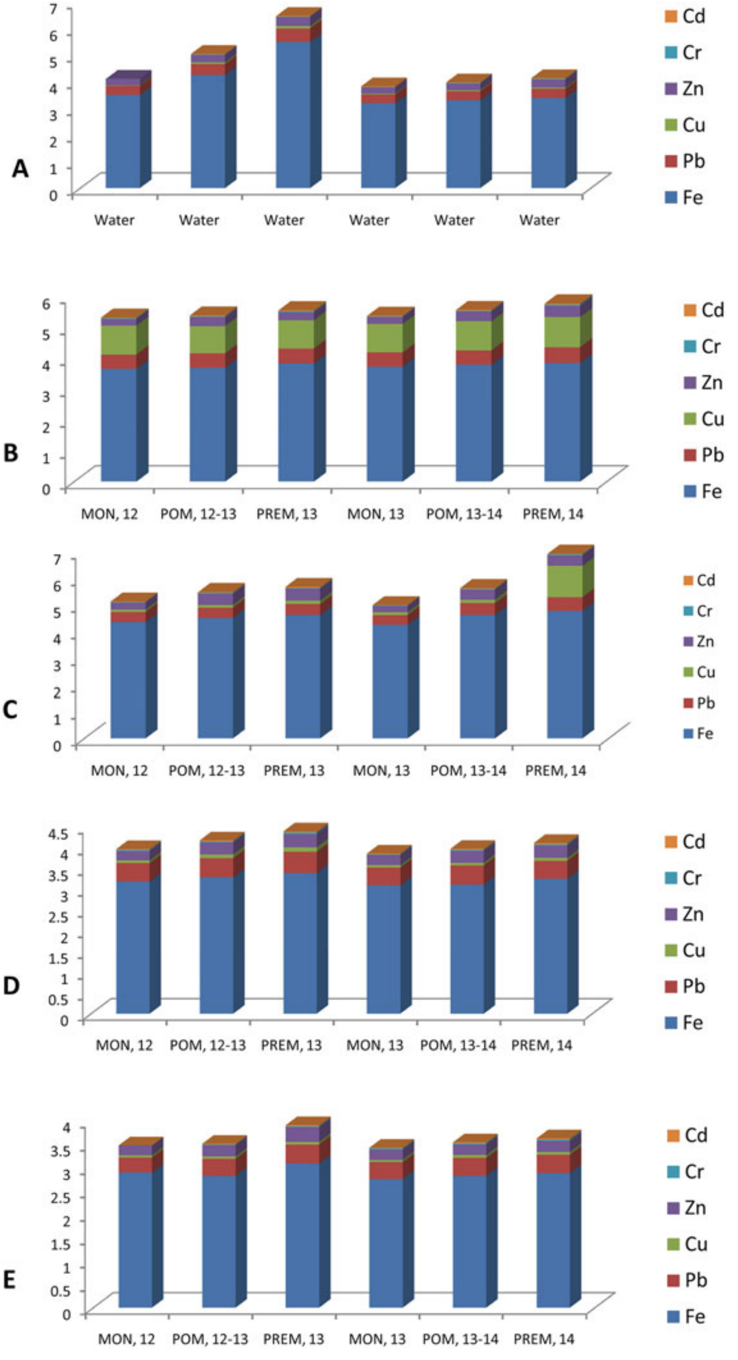

Fig. 5.11 Seasonal dynamics of heavy metal concentrations in water at different contrasting study sites along a trans-boundary river of West Bengal, India – the Subarnarekha River

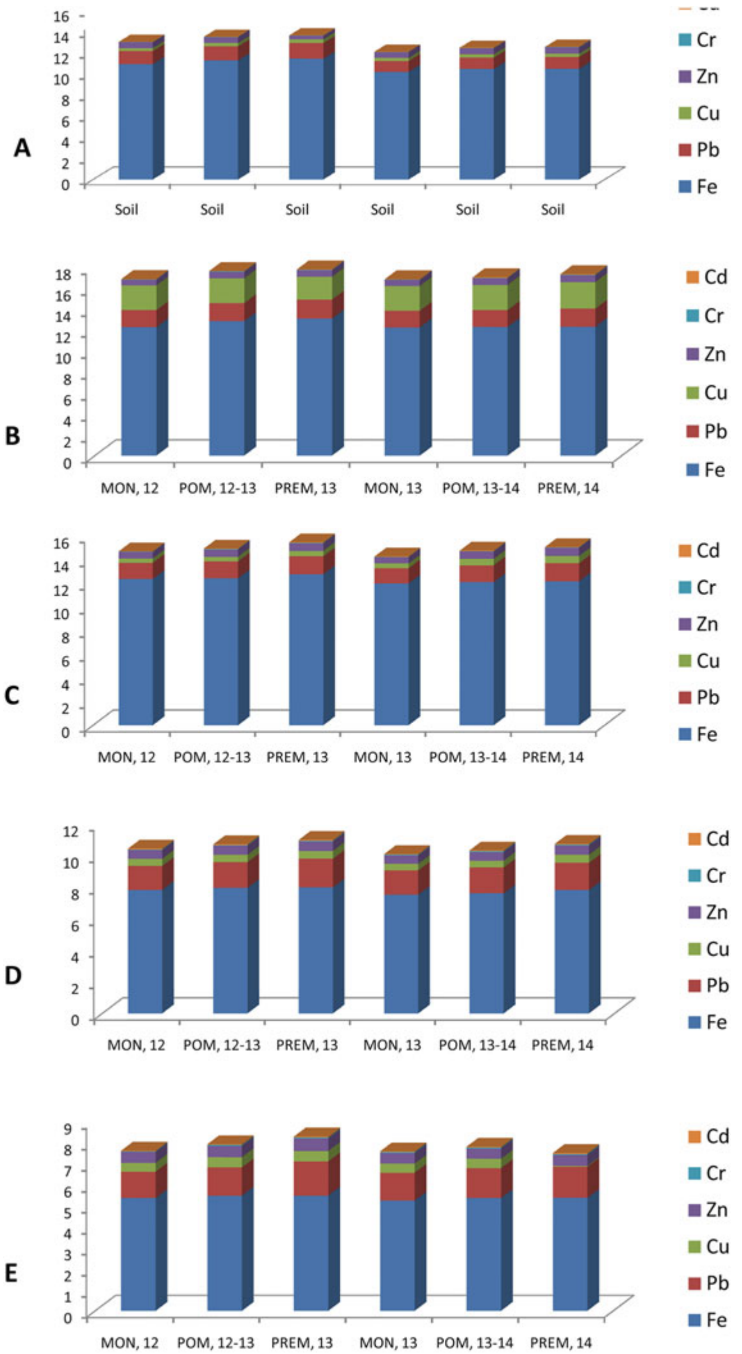

Fig. 5.12 Seasonal dynamics of heavy metal concentrations in soil at different contrasting study sites along a transboundary river of West Bengal, India – the Subarnarekha River

Fig. 5.13 (**A**) Washing and bathing of domestic animals – buffalos in herd (**B**) Washing of big mammals like elephants in the streams (**C**) Immersion of Goddess idols (**D**) Lifting of sands from the river bed (**E**) Fishing coupled with eutrophication (**F**) Massive eutrophication leading to reduction of depth and water volume. (**G**) Washing of cars/large soil digging machines (**H**) Activities of fishing trawlers (**I**) Traditional water transport-related activities. (**J**) Dredging activities (**K**) Uncontrolled ecotourism (**L**) Large-scale bank erosion

Ward and Stanford (1979a, b) have pointed out that more than **12,000** solid built structures greater than **15 m** height have been constructed on the major rivers of the world, impounding a water mass equivalent to greater than one third that held in the atmosphere (**= 4000 km^3**), and thereby converting most of those river systems like that of human made water impoundments.

Such alterations of river systems along with the problems of point and non-point pollution, large-scale water abstractions altered flow regimes, flow reversals, changes in the species composition of different biota, introductions of exotic species, and so on have established the fact that the lotic ecosystems all over the world have been very much threatened.

5.4 River Pollution: Impacts and Imprints on Biota

Not only the deteriorating water quality in the river ecosystem impart harmful effects on biota but also the diversity and distribution patterns of different organisms (flora, fauna, and even microbes)in temporal and spatial scales can modify the riverine environment. For example, macrophytes of river provide habitat, shelter, and indeed food for many other animals including fish and smaller plants (algae fungi, cyanobacteria, etc.) which promote higher biodiversity development, but sometimes they experience negative interactions with other biodiversity components demonstrating detrimental effects on the survivability of others (swans may destroy macrophytes, blooms of some algae produce toxins which may kill fish, etc.). The natural riverine flows in its normal state enjoy natural balance among plants and animals. Some of them are interdependent; some are competing, and some are independent. Anthropogenic intervention alters the habitats of the organisms dislodging the native and indigenous species from their preferred habitats paving the way for the arrival, settlement, colonization, and proliferation of alien/invasive ones and thereby threatens the functioning of the ecosystem in course of time.

The ecological changes of river ecosystem can also be monitored and evaluated biologically after making an assessment of intricate relationships among biological, physical, and chemical components of the same ecosystem. The plants and animals in a river or stream having little mobility receive and utilize water constantly during their lifetime, and, in such process, accumulation of several physicochemical messengers within them at a given period reflects the cumulative effect on them. Chemical analysis reveals the general physicochemical state of water or soil, for examples, oxygen, nitrate, cadmium, and perhaps up to several dozens of other substances which undertake bioaccumulation so that an assessment of the integrated effects of all those substances present in the water is possible. Since they are living, biological information derived on them are less precise than those estimated chemically (Biswas and El-Habr (1993); Biswas (1972, 1975, 1978); Bond and Midgley (2000); Chakraborty (2013); Chakraborty et al. (2013); Heino et al. (2009); Heino (2013); Hering et al. (2004, 2010); Hohensinner et al. (2004, 2005a, 2005b, 2008, 2011); Keller (1975, 1978); Paria et al. (2017, 2019); Petts (1984); Pimentel (1961).

5.5 Differential Impact of Pollution Pressure on Plants and Animals of Rivers

The effect of the same pollutant on the biological organisms will vary both in respect of the quantity and the quality of the receiving water: the quantity is important because an effluent diluted a thousand times is much less harmful than one diluted twice. The quality is also important because the physicochemical properties of the soil and water of rivers or streams vary on among different seasons of the year and in between ecozones located in the stretches of river flows.

Fig. 5.14 (**A**) Deposition of coal-based slags/sludges on the bank of Subarnarekha River discharged from the Hindustan Aluminium Industry (**B**) Stabilization of deposited slags/sludges

5.5.1 Differential Biological Responses Against Pollution Pressure

Different parts of the ecosystem are affected differently by pollution. Rooted macrophytes absorb chemicals from both soil and water. Generally, pollutants are most concentrated in silt, and clay and least on coarse particles such as sands and water. Therefore macrophytes and animals with higher biomass usually reflect properties of soil more than water. Concentration and intensity of harmfulness of pollutants in the effluents can be reduced within the living organisms within short periods while it takes some years for polluted silt to be washed out. Different horizontal layers of river communities are therefore affected differently by pollutants.

Microorganisms of some sort are found throughout. Macrophyte with their roots otherwise go down furthest, deep in the water bottom and provide the shelter and food to several forms of animals such insects, molluscs, annelids which are designated as periphyton. On the ground surface are macro-invertebrates, some of the non-rooted mosses, diatoms, other algae, etc., and of course the lower parts of flowering plants, rooted or non-rooted. The main body of the water is inhabited by a galaxy of fish, plankton, invertebrates, macrophytes, algae, diatoms, and also other life forms belonging to higher chordates such as, diving fowl amphibia, reptiles and mammals etc. On the water surface, there are floating macrophyte and other plants and various invertebrates such as water skaters and duck. Finally, above and beyond the water surface extending even to the terrestrial zones, yet still being the part of the river ecosystem, acts as habitat for vegetation herbs and trees of and beside the bank; they support the invertebrate populations which may spend part of their life cycle in the river and also such biotopes are used by the otters, dippers, kingfishers, and other mammals and birds as resting places, burrows and homes.

5.6 Pollution Status of Indian Rivers: Types and Sources

Noted ecologist Kendeigh (1975) has classified pollution in aquatic bodies into five main categories: (**1**) natural; (**2**) siltation(as erosion products); (**3**) organic pollutants (domestic and animal sewage, biodegradable organic compounds, wastes from food

Fig. 5.14 (continued) by the seasonal grass, Kash – an indicator of degraded land (**C**) Emission of atmospheric pollutants from the industry on the bank of river Subarnarekha (**D**) Flowing of industrial toxic effluents through several channels towards with riverine flows (**E**) Mixing up of the industrial effluents with the main body of Subarnarekha River at Ghatshila, in the state of Jharkhand (**F**) Dumping of solid wastes at the bank of river Subarnarekha from the copper industry (**G**) Unwanted accretion of sediments in the river bed (**H**) Erosion on the bank of river leading to develop elevated CHARA on river bed (**I**) Releasing of highly loaded water with toxic chemicals as revealed from the color from the industry to the riverine flows (**J**) Emission of pollutants from the industry by the side of riverine flows

Table 5.1 Major anthropogenic activities affecting river systems

Supra-catchment effects Acid deposition Inter-basin transfers
Catchment land-use change Afforestation and deforestation Urbanization Agricultural development Land drainage/flood protection
Corridor engineering Flow regulation – dams, channelization, weirs, etc. Dredging and mining
Instream impacts Organic and inorganic pollution Thermal pollution Abstraction of water Navigation Exploitation of native species Introduction of alien species

Table 5.2 Point sources and the expected contamination of groundwater

Source	Inorganic contaminants	Organic contaminants
Urban areas	Heavy metals and salts	Oil products, biodegradable organics
Industrial sites	Heavy metals	Chlorinated hydrocarbons, hydrocarbons, oil products
Landfills	Salts and heavy metals	Biodegradable organic xenobiotics
Mining disposal sites	Heavy metals, salts and arsenics	Xenobiotics
Dredged sediment and sludge disposal	Heavy metals	Xenobiotics
Hazardous waste sites	Heavy metals (concentrated)	Concentrated xenobiotics
Leaking storage tanks	–	Oil products (petrol)
Line sources (motorways, railways, sewerage system, etc.)	Heavy metals, salts	Oil products, pesticides

processing plants, slaughter house, agriculture runoff, oils, etc.); (**4**) industrial pollution (inorganic chemicals – tanneries, breweries, paper and pulp mills, gas plants, mines, petroleum industries, etc.); and (**5**)thermal pollution (from the elevation of environmental temperature) (Figs. 5.1, 5.2, 5.3, 5.4, 5.5, 5.13, and 5.14).

The rivers form a part and parcel in daily life of Indian society by not offering as a means of transport, recreation, power generation, and reservoir of natural resources alongside their influence on the Indian society in religious matters. The riverside used to accommodate huge number of people during festive seasons and occasions

Table 5.3 Some sources and causes of water quality deterioration

Effluent	Factors affecting water quality deterioration
Domestic sewage	BOD, suspended solids, ammonia, nitrate, phosphate
Vegetable processing	BOD, suspended solids, color
Chemical industry	BOD, ammonia, phenols, non-biodegradable organics, heat
Iron and steel manufacturer	Cyanides, phenols, thiocyanate, pH, ammonia, sulfides
Coal mining	Suspended solids, Iron, pH, dissolve solids
Metal finishing	Cyanide, copper, cadmium, nickel, pH
Brewing	Suspended solids, BOD, pH
Dairy products	BOD, pH
Oil refineries	Heat, ammonia, phenols, oil, sulfide
Quarrying	Suspended solids, oil
Power generation	Heat

when people assemble there in thousand for a happy reunion, divine worships, offerings, and religious celebrations. All these have made the Indian rivers as symbols of Indian culture, heritage, tradition, and prosperity. In India, perennial rivers, arising from fixed headwaters have their origin from the great glaciers in Himalayas. For instance, the Ganges has its origin from the Gangotri glaciers in the snowbound Himalayas at a height of about **7000** m above the mean sea level. Owing to rapid pace of increase of human population, poverty, unplanned urbanization, and industrialization, the precious freshwater resources especially riverine water of India are being polluted considerably through the dumping of solid wastes, releasing of sewage, industrial effluents, a wide array of synthetic chemicals, heavy metals, pesticides, etc.

The environment of organisms living in freshwater consists of a number of habitat factors such as temperature, the intensity and quantity of sunlight, **pH**, dissolved oxygen, etc. which limit the distribution, diversity, density, population fluctuation, community interactions, etc. (Mukherjee 1986; Biswas 1981). Besides, several other modes river pollution have been resulted from mining activities (sand, coal etc.), immersion of idols, transportation with mechanized hydrocarbon-based fuels, washing of automobiles, and even through domesticated animals, deforestation followed by massive soil erosion etc. (Figs. 5.13 and 5.14).

5.7 River Ecosystem Health: An Indicator for Eco-assessment of River Ecosystem

The ecological health of a river means a normal state of interaction among different structural components of the ecosystem by which both the stability and natural productivity of the riverine ecosystem is maintained. In other words, it can be postulated that river health, a measure of ecological health of catchments or basins, in turn acts as an indicator of environmental and societal health as river is being considered as the life line of human civilization. Existence and maintenance of ecological health of rivers through sustainable management integrating the societal, cultural, and economic values are intimately connected with the well-being of human beings in all respects. In the earlier days of human civilization, the quest for meeting the human needs did not pay that much attention for the protection to the aquatic ecosystems. Since the time of industrial revolution in Europe, different anthropogenic activities brought about undesirable changes on river health, jeopardizing the natural viability of rivers, their structural integrity, trophic complexity, and the ecosystem functioning.

Several ecological issues such as habitat fragmentation and loss, extinction of species, alteration of community interactions, eco-degradation due pollutants load, etc. have resulted disruption in ecological integrity, sustainability of the ecosystem functioning, and causing threats to ecosystem health considerably. As awareness and understanding of these burning issues pertaining to environment have improved, society no longer has an excuse not to address concerns brought about by the impacts of human activities on river systems. Shifts in environmental attitudes and practice have transformed outlooks and actions towards revival of aquatic ecosystems. Increasingly, management activities work in harmony with natural processes in an emerging "**age of repair**," in which contemporary management strategies aim at enhancing fluvial environments either by returning rivers achieving their former eco–geo–biological characters to a certain extent, or by establishing a new, yet functional environment. Notable improvements to river health have been achieved across much of the industrialized world in recent decades.

However, a multitude of ecological issues such as salinity invasion, flow regulation, loss of habitat and species diversity, erosion and followed by higher water turbidity, and over allocation and over exploitation of water resource significantly led to draw societal and political attention all over the globe. Developing a meaningful framework to recognize, understand, document, and maintain this geodiversity have appeared to be the prime focus in addressing pollution and perturbations in rivers. Paying proper attention to those of existing conservation rules and regulation, emphasis is placed on the need to maintain the inherent diversity of riverscapes and their associated ecological values. The highest priority in the eco-management of rivers rests on looking after good condition remnants of river courses so that sustainability of rare or unique reaches of rivers regardless of their condition be achieved.

Unless management programs respect the inherent diversity of the natural world, which are based on an understanding of controls on the nature and rate of landscape change, and also to attach importance to find out the reasons behind the alterations to one part of an ecosystem which in turn affect other parts of that system in the pursuit to undertake a sustainable river management. In such context, river management programs that work with natural processes will likely yield the most effective outcomes, in environmental, societal, and economical terms. In order to meet and also to overcome those challenges, sustainable, holistic multifunctional, catchment-scale river management programs have emerged in recent decades (Newson 1992).

5.8 Pollution of Rivers and Its Legacies: Historical Perspectives

Wastes having multifarious sources (industrial, municipal, agriculture, domestic, biomedical, etc.) are chemically classified as organic (mostly degradable) and inorganic (mostly non-degradable). Different wastes impart different impacts leading to different environmental consequences. Wastes having organic wastes, both solids and liquids after being disposed into the aquatic ecosystems, undergo decomposition process resulting to the production and release of nutrients. Centuries ago, smaller and mid-sized rivers are subjected more onto this problem of higher nutrient loading than the larger rivers with higher depth, currents, and volume of water.

In Medieval period, all castles and monasteries without having proper sanitary systems had direct connection between their latrines and local rivers (Haidvogi 2018). In the early fourteenth century, the Seine River of Paris was turned into an infectious and foul canal on receiving effluents from the city (Mieck 1981). The quantities of wastes were, however, considerably smaller before the 1900s. Since time immemorial, excreta of both human and animal excreta have been appearing appeared as valuable sources of nutrients after being processed scientifically for agricultural production. The late nineteenth century witnessed a general practice of disposing and even direct flushing of human and animal excretes to nearby flowing water bodies. At that point of time, discoveries of the Justus von Liebig, 1983, on the role of nutrients for plants, especially on the contribution of phosphorous fertilizer, had opened up new vista in European agriculture.

However, the invention of the Haber–Bosch process in **1910** had appeared to be great relief for the farmers on their overdependence on natural fertilizers. This had far-reaching consequences for rivers. The major portion of nitrogen supply for agricultural production (**9100** tons/year) was mostly derived from the large sewage farms along the Seine banks on the downstream of Paris during that period (Barles 2007). Historical legacies of the release of toxic and hazardous substances because of anthropogenic activities into rivers have received global recognition. One major evidence in support of this is chloride pollution of the Rhine River that was persisted for several centuries, compelling France to face and encounter a problem of the rise of salinity on its Alsace aquifer (Vörösmarty et al. 2010, 2015).

Such long-term legacies of historical events have enabled the river ecologists and environmental managers to undertake proper scrutiny of the pollution-mediated ecological problems in order to device proper eco-management strategies (EEA 2012) pollution with heavy metals from mining and ore processing has been relevant throughout history. Since the sixteenth century, both in Europe and America, several studies on the mining of mercury to strengthen the activities for the large-scale gold and silver exploitation and production, had resulted considerable eco-degradation of several terrestrial and aquatic ecosystems (Torkar and Zwitter 2015). Investigation on the long-term pollution effects of the Slovenian mercury mine on Idrija River and its biotic components mainly on fish showed that sediments after being contaminated with the pollutants load were moved on to downstream which are got accumulated finally accumulated in the sediments of the northern part of the Gulf of Trieste (Gosar 2008; Foucher et al. 2009).

5.9 Environmental Perturbation: Threats to Biodiversity

Anthropogenic influences imperil the biodiversity of rivers and their associated wetlands at a variety of scales. The main threats are:

1. Deforestation and drainage basin alteration that destroy or degrade instream and riparian habitats
2. River regulation, including flow modification and impoundment creation by dams, water extraction for irrigation, different types of pollution, etc.
3. Overharvesting (mainly of fishes and reptiles)
4. Global climate changes. The combined impacts of these threats have been proved to be more damaging than the sum of each

The assemblages of different biodiversity components initially put resistance by virtue of their combined strength of different biological attributes and also by way of varied behavioral manifestations.

5.10 Environmental Perturbations: Through the Direct Manipulation of Habitats in the River Ecosystem

Since the time immemorial, river ecosystems have been used by different ways to fulfill the direct and indirect needs of human being by way of channel dredging, alteration of flow patterns, overexploitation of biota, construction of dams and barrages, bank revetments that hamper river–floodplain interactions (Collins et al. 1997; Hohensinner et al. 2003; Collins and Anthony, 2008). Such manipulation of riverine beds tend to result a shift of the relative proportions of different habitat types which in turn reduce the habitat diversity and habitat heterogeneity through the cross-section of geo-morphological modification channel, removal of complex shelter zones for fishes and other biota, damages the spawning and rearing grounds for fishes, and ultimately causes a reduction of primary and secondary production (Fig. 5.13).

Another significant manipulation of river ecosystems is altering the spatial distribution of aquatic species by blocking fish migration or transplanting fishes, loss, or removal of species from the riverine landscape through over harvesting, hatchery practices, or habitat modification can shift the abundance and species composition within the riverine ecosystems and the potential for dispersal to upstream and downstream reaches. Such alteration in biotic community interactions based on the changed scenario in species abundances which in turn alter food webs and productivity of river ecosystems. For example, dams that block upriver migration of Pacific salmon reduce inputs of important nutrients and energy for aquatic and terrestrial food webs (Schindler et al. 2005).

5.10.1 Deforestation and Degradation of Drainage Basin

While the fauna of tropical Asian rivers is adapted to seasonal flow fluctuations, unregulated rivers do not necessarily have natural discharge regimes. The consequences of the misuse of drainage basin coupled with deforestation resulted increased runoff, sedimentation, and flash floods throughout the region. In particular, the effects of deforestation interact with seasonally variable river flows, increasing the frequency and intensity of flood flows with direct and profound consequences for human inhabitants of floodplains (Fig. 5.5). The loss of forest cover in tropical Asia has important implications for river conservation since a significant proportion of the rich fish fauna of the region exploits allochthonous foods in inundated forests. Increased turbidity limits primary production, and results in lower fish populations. Changes in habitat characteristics of drainage basins do not affect forests only; floodplains are also modified or degraded.

5.10.2 River Regulation and Dams

Fishes and other elements of the lotic fauna are adapted to the floods that are typical of rivers in monsoonal Asia. Although there is some inter-annual variation in flood peaks, the flood pulse is not a disturbance in the ecosystem. Instead, significant departures from the typical pattern of seasonal flow fluctuation can be regarded as disturbance. This sets the scene for conflict between the needs of humans and of riverine biota. As many Asian rivers drain degraded and deforested catchments, the desire to limit peak flows by trapping flood waters behind huge dams is understandable. The conflict between human desires to limit or control flows and the requirements of the ecosystem for natural or semi-natural flows is heightened in Asia by high population densities that place severe constraints on the preservation of riverine biodiversity. The recent trend in Asia has been towards more and bigger dams, culminating in the Three Gorges Scheme on the Yangtze-the largest dam in the world, which will impound Asia's largest river. A predictable result of these dams is that natural flow variability – to which the fauna are adapted and upon which they depend – will be smoothed out. This averaging of flows is significant because ecological responses to environmental change may be nonlinear: fish breeding migrations, for example, may not begin until flows have passed a critical threshold.

Landings of *Tenualosa (Hilsa ilisha*) likewise dwindled to almost nothing after the completion of the Farakka Barrage on the Ganges. The impacts of river regulation involve not only barriers to longitudinal migration but also limitations on lateral movements. Fisheries in the Jamuna River (Bangladesh) declined by over **50%**

when flood control embankments reduced fish access to floodplains, and the major carp fishery of the Ganges practically reduced alarmingly after blocking the seasonal inundation of the floodplain. Most fishes adapted to the fluctuating discharge of a river will not thrive in a stagnant impoundment. High fisheries yields reported from Asian reservoirs depend on cage culture, stocking (usually of major carp), or introduction of exotic species. Such practices are accompanied by a loss of native biodiversity. Pollution of water varies considerably through tropical Asia. However, most major rivers, as well as a host of minor streams, are grossly polluted, and some are among the most degraded in the world.

5.10.3 Erosion and Sediment Supply

Erosion processes are commonly classified as three types (Dunne and Leopold 1978) as mentioned below:

1. Soil creep (the gradual down slope movement of the soil mantle by gravity)
2. Surface erosion (including sheet wash, rilling, and gullying
3. Mass wasting (landslides) and surface erosion are being focused because they are influenced by many human activities including logging and road building, tilling and grazing practices, and land clearing and construction activities (Bradford and Huang 1994; Imaizumi et al. 2008)

By contrast, human influences on soil creep have not been shown to impact streams and are not a target of restoration activity. Mass wasting processes such as land sliding are episodic, driven by storm event frequencies and high spatial variation in number and failure potential of landslide sites (Bergstrom 1982; Benda and Dunne 1997a). Surface erosion on bare soils is more predictable than mass wasting because it occurs during virtually all rainstorms and snowmelt, and the severity of erosion varies predictably with rainfall intensity, slope, and soil type (Dunne and Leopold 1978).

5.11 Pollution from Agriculture and Non-point Sources

It is largely uncontrolled and, as cities and industries expand without adequate waste treatment facilities, rivers receive increasing quantities of effluent (Tables 5.2 and 5.3). Fish kills (due to industrial wastewater, pesticides, etc.) occur frequently during the dry season when water flows are insufficient to dilute pollutants. Things are no better in India. Fish kills are common in the Ganges, which ranks third in the region by flow volume and is probably the most polluted large Asian river. With approximately **400** million people in the catchment, human population density is high, and **600** km of the river course is grossly polluted by sewage, animal wastes, and industrial effluents. Most industries discharging into the river lack operational waste treatment plants, and some cities (the holy city of Varanasi). Environmental degradation has continued despite the fact that the Ganges is viewed by Hindus as sacred, and pilgrimages to bathe in the cleansing river waters are an important religious practice. This contradiction epitomizes the challenges facing those wishing to protect Asian rivers.

Population declines began decades ago, and stocks have collapsed in recent years so that the fish is now endangered. Increased availability and use of synthetic chemicals, rather than natural poisons (such as rotenone extracted from plants), may be a contributing factor also. Motorboats and refrigeration technology allow the exploitation and marketing of previously inaccessible stocks. They contribute to overharvesting by reducing the extent of refuges in which stocks are not fished and from which recruits are derived. Unsustainable fishing practices, such as the use of ever-finer meshed nets and overfishing of spawning grounds, combined with the application of poisons, explosives, and electric shocking, have led to marked declines in major carp recruitment, the damage of such fishing practices cannot be separated from the effects of dams and fish kills caused by pollution. Alteration in flow and sediment characteristics because of construction of dams has reduced the spawning success downstream.

Global climate change will modify river discharge patterns which in turn impart negative impact on riverine biota in tropical Asia ere. The influence of water quantity on the habitat, spawning ground, foraging behavior and life history of tropical fishes, and other associated faunal components seems to parallel the importance of temperature to fishes in temperate latitudes. Possible scenarios of climate change include wetter wet seasons and drier dry seasons, with an increased frequency of extreme flow events. As the fish catches from rivers have mostly found to be positively correlated with the extent of inundated floodplain, the increased frequency of extreme flow events will increase the variability of fisheries yields. In addition, lower flows during the dry season will concentrate pollution loads in many rivers. The combination of extreme flow events, the deforestation near drainage basins construction of dams and flood control projects together lead to deplete aquatic biodiversity.

5.12 Spatial and Temporal Variation of Water Pollution

Pollution of water quality varies considerably through tropical Asia. However, most major rivers, as well as a host of minor streams, are grossly polluted, and some are among the most degraded in the world. Antipollution legislation is in place in some countries, but is weak and/or poorly enforced. Pollution from agriculture and non-point sources is largely uncontrolled and, as cities and industries expand without adequate waste treatment facilities, rivers receive increasing quantities of effluent. Many rivers are oxygen-poor for much of the year. In parts of Peninsular Malaysia and Java, some rivers are so severely degraded that fisheries have collapsed. Fish kills (due to industrial waste water, pesticides, etc.) occur frequently during the dry season when water flows are insufficient to dilute pollutants. Tributaries are more heavily contaminated than the main channels where dilution of pollutants is greater.

Most industries discharging into the river lack operational waste treatment plants and some cities (the holy city of Varanasi) lack sewage treatment facilities entirely. Environmental degradation has continued despite the fact that the Ganges is viewed by Hindus as sacred, and pilgrimages to bathe in the cleansing river waters are an important religious practice. Asia accounts for more than half of the global total of inland fisheries landings. China, India, Bangladesh, and Indonesia are the four most important inland fishery countries in the world,. Available figures do not separate yields of aquaculture-based fisheries and enhanced fisheries (in which stock is added to water bodies) from natural capture fisheries nor do they distinguish reservoir from river fisheries. The dispersed and informal nature of many fisheries leads to underreporting of landings, and subsistence fisheries are rarely reported. Higher catches in Asia reflect heavy exploitation of virtually all categories of freshwater habitats and capture fisheries based on wild stocks, have appeared to be at or exceeding the limits of sustainable yield.

5.13 Eco-degradation of Rivers: Consequences of Pollution in Indian Perspectives

The ecological degradation of Indian rivers has been resulted primarily due to different forms of anthropogenic interventions, such disposal of both municipality and industrial wastes, water abstraction, unregulated lifting of groundwater from the river basins, construction of dams and barrages, siltation, soil erosion due forest degradation in catchments, and different types of point and non-point pollution (Paria and Chakraborty 2019). Alterations in the "**River Flow Continuum**" may change the ecology of the river in the long run (Petts,1984).

5.13.1 Water Supply from Rivers

Rivers were essential water resources in particular for various commercial purposes. In urban areas, they became centers of economy. River water has been in use since the inception of human civilization by the washers, tanners, dyers, food industries, beer brewers, and slaughter houses, for the purpose of cleaning and washing. All those water-based activities led to result serious conflicts in respect of water demand, sharing and utilization in between water polluters and water users (Billen et al. 1999). Supply of drinking water was although primarily met from local groundwater sources, the surface waters could be used more systematically and scientifically in order to reduce the pressure on the ground water aquifers. (Kraikovsky and Lajus 2010). Uncontrolled population growth coupled with unplanned urbanization has been identified as the prospective reasons for the enhanced pressure on drinking water supply during the early nineteenth century. Excessive usage of water beyond the permissible amount directly as drinking water and indirectly for other human purposes proportionately increased the generation of the total amount of wastewater which ultimately finds their ways into rivers. Newly built centralized sewage systems have been in use to resist point source pollution, especially in the urban areas since the late nineteenth century, with an aim at controlling hygienic nuisance and infectious diseases, such as cholera.

5.13.2 Environmental Impacts on Water Resource Systems: Roles of Different Pollutions

As the world's population continues to grow, it is the demand of the time to assess the present days environmental issues in terms of development with much care so that along with meeting the needs of the moments, carrying capacity of resource bases should be kept in reserve for fulfilling the requirements and aspirations of the future generations, i.e., for achieving truly sustainable development. It is clear, however, that some quite unsustainable development policies and practices, particularly concerning with water management, have been followed.

The essential role of science in continued socioeconomic development, an area in which water resources are essential, is not a simple one. In managing our resources, it is evident that not only does nature affect humans, human activities can also have devastating results on nature. It has become evident now, for example, that some human activities appear to be leading to possible major climate changes.

The probable consequences are not yet known with certainty, but it is clear that climate change would result in a redistribution, in time and space, of our water resources. To understand this change and be able to cope with it, we must have a much stronger scientific understanding of the processes involved. The approaching problems, coupled with the many existing environmental stresses (e.g., land and water pollution, erosion and sedimentation, and natural and artificial hazards), emphasize the need for continued development of human potentials, education, training, and public understanding as essential elements in a major international effort.

The responsibility of water scientists and engineers, then, must be, with full consideration of the changing environment,

1. To generate and maintain information on the availability of water resources
2. To assess, monitor, and predict the resulting quality of water bodies and water-related environment
3. To develop a better scientific understanding of the effects of human activities that influence hydrological regimes (especially those resulting from climate change)
4. To provide decision-makers with the necessary information in properly constructed formats so that they realize the problems and the importance of the

hydrological sciences as a basis for proper environmental management, especially of water resources and react appropriately

5.13.3 Relevance of Chemical Input into River Ecosystems

The Millennium Ecosystem Assessment for Rivers has assessed the relevance of chemical impacts on streams and rivers, initially by enlisting different toxic chemicals under both organic and inorganic categories out of the major groups of pollutants (Fynlayson and D'Cruz 2005).

Alongside, attempts were made at recording on proper identification of the leading threats to the river ecosystems with pesticides, nutrients, and metals in tune with the global environmental changes (Vörösmarty et al. 2010). Besides, an array of other toxic chemicals have been found to occur profusely in the aquatic environment which imposed strong deleterious impacts on the life processes of living organisms through endocrine disruption and thereby disrupt trophic linkages on populations and communities (Kidd et al. 2007). Moreover, long-term chronic exposure from hydrophobic chemicals also poses similar harmful effects as rendered by acute short-term toxicity (Malaj et al. 2014). These have been evidenced for an exposure of low levels of estrogens, released from the wastewater treatment plants (**WWTPs**) mostly housed at the downstream causing a collapse of a fish population after **3** years of chronic exposure.

5.13.4 Surface Water Pollution

The maintenance, eco-management, and supply of water quality of surface water resources have become increasingly important. Considering the safety of the riverine ecosystem in general and human health in particular, serious attention is being made in identifying many new problems with the prospective mitigation strategies and also innovative approaches are being taken for their prediction during a time span of more than 50 years. Besides, the pollution from point and non-point sources such as agriculture and deforestation, have triggered the scientific views towards considering the problem of pollutant precipitation from the atmosphere. Simply adding water quality parameters to classical hydrological formulas is no longer sufficient. Detailed small-scale hydrological investigations of a different nature are needed to predict pollution pathways.

It is necessary to research the ways in which polluting substances, under certain conditions, are transformed, combined with other substances, temporarily retarded somewhere, and then suddenly released. Transport and transformation processes of non-point pollutants are greatly influenced by vegetation, land use, and soil processes, including snowmelt aspects, and these continue in unsaturated and saturated zones of soils, in rivers and lakes, and, finally, in the estuaries in the brackish interface between the river and the sea. Flow patterns on hill slopes and within the soil profile depend on the interactions between the modified rainfall inputs described previously and the drainage basin geology, pedology, and topography. The nature of these interactions determines the division of hill slope outputs into quick flow and base flow streams, and, thus, has important implications for the form of the storm hydrograph and sediment and solute losses from arid and forest catchments.

There is a fundamental distinction between infiltration-excess overland flow and the subsoil and subsoil-related processes, which are highly dependent on site-specific soil moisture and moisture-retention characteristics. The next important hydrological division is at the soil surface. If rainfall intensities exceed the infiltration capacity of the soil, the unabsorbed water (minus any losses from evaporation of surface water stores), once the surface detention capacity has been exceeded, runs off down slope via the hydrological process known as infiltration-excess overland flow. In forest areas, however, infiltration rates are usually high owing to the high-hydraulic conductivity of the forest litter layer. Further, hydrological processes interact with sediment transport effects, as small-scale landslides in saturated stream head hollows in humid temperate environments appear to lead to channel network extensions. Different flow routes clearly have different residence times and, therefore, might be expected to show different solute concentrations. Generally, macropores tend to create preferred paths through which water moves as channelized flow, and thereby bypass the soil matrix. This biphasic flow regime (where water flows rapidly through the large pores, while remaining relatively immobile in the fine pore spaces) by restricting the leaching of solutes from the soil matrix, play an important roles in controlling the passage of water flows in riverine system.

5.13.5 Groundwater Pollution

Nowadays, majority of the research studies on the river pollution in general and ground water contamination in particular have focused on the mode of movement of different toxicants in groundwater. Several ecological models have tried to explain the mode of saltwater intrusion and also the pattern of leachate migration from waste disposal sites. Groundwater pollutants can be categorized as bacteria, viruses, nitrogen, phosphorus, metals, organics, pesticides, and radioactive materials. This section covers information on subsurface transport in a general way.

5.13.6 Migration of Pollutants in Aquifers

Contamination groundwater by the vertical movement of toxic substances does not take place not only by advection but also by dispersion too. Advection (also known as convection) deals with the transport of a solute at a velocity equivalent to that of groundwater movement. Dispersion refers to the mixing and spreading facilitated by molecular diffusion and also partially by the variations in velocity within the porous medium. It can simply be defined as the movement of solutes due to differential velocity from pore to pore at high velocities,

5.14 Climate Change and Its Impacts in Riverine Ecosystems

Global warming is a growing threat to biodiversity all over the world (IPCC 2000). Rise in temperature affects the biology of a species at its molecular, physiological, and biochemical levels thereby altering its distribution patterns as well as community interactions (Das et al. 2004). Besides, temperature elevation, some other factors like fragmentation of habitat because of ongoing changing patterns of land uses have compounded the problem and resulted to the non-adaptability of species and ecosystem to adapt.

Extinction of about **75** species from tropical America because of fungus outbreaks which were greatly enhanced by warmer temperatures indicating indirect linking of the impact of climate changes on biodiversity (Archer and Rahmstorf 2010). The **IPCC**, 2007, concludes citing evidential facts that the climate driver extinctions and widespread range retractions result invasion of exotic species from warmer regions. Changes in the oceans include a pole ward shift of fish, plankton, and algal species alongside warming of ocean water (Archer and Rahmstorf 2010). Coastal zones are particularly vulnerable to the impact of climate change mainly because of warming of water, a reduced nutrient supply of the sunlit surface waters due to more stable layering of water (a thin layer of warm water tends to float on top, preventing mixing), sea level rise, increased risk of deceases and acidification. Moreover, coastal ecosystems are threatened by suffocation as the increased stratification and reduced mixing cause a critical loss of oxygen in the water-hypoxic event (Archer and Rahmstorf 2010; IPCC (2007b); EEA (European Environment Agency) (2012); Weatherhead and Howden (2009); Lal (2004); Lal (2005).).

5.14.1 Climatic Change and Its Effect on Water Resources

The climatic changes foreseen and the probable consequent changes in the physical environment show that our present understanding of water resources and of the hydrological cycle is not sufficient. Prediction of new hydrological regimes will require a better understanding of the systems and a better capability for quantitative analysis than is now available. More than ever before, decision-makers must be made aware of the importance of water problems, and they must be given recommendations for action based on sound scientific rationale. Hydrology and the study of water resources for sustainable development in a changing environment open a new era in the development of water sciences and management, and are designed to provide an international focal point for a broad coordinated effort in hydrology and the scientific bases for water management. They represent the combined efforts of national, regional, and international governmental organizations (Figs. 5.6, 5.7, 5.8 and 5.9).

5.14.1.1 Climate Change and Surface Water Temperature: Case Studies on Sundarbans, India

The closing decades of twentieth century and early years of the current one have witnessed an unusually warm environmental condition, whereas the last **30** years have been the warmest (Houghton 2009). The Intergovernmental Panel on Climate Change in its **2007** assessment status report mentioned that "Warming" of the climate is un equivocal, as is now evident from observations of increases in global average sea level. The past couple of centuries have experienced enormous amount of emission and accumulation of **CO_2**, more substantially over the past **50** years because of different human activities especially the burning of fossil fuels, coal, oil and gas, together with widespread deforestation. Because **CO_2** is a good absorber of heat radiation coming from the earth's surface, increased **CO_2** acts like a blanket over the surface, keeping it warmer and the resulted increased temperature also increased the temperature of water vapor in the atmosphere leading to the formation of more blanketing and causing it to be even warmer. The emission of methane also because of incomplete decomposition of organic waste mining and agriculture also compounded to this problem (Houghton 2009).The trend of increase of **CO_2** in the atmosphere depicts an increase of **315 ppm** in **1950**s to **361 ppm** in **1996** which reached to **379 ppm** by **2006**.

The rate is found to have been accelerating, growing **20%** faster in the period of **2000–2004** than the growth rate was in the **1990**s (Archer and Rahmstorf 2010). During the decades of **1980s** and **1990s**, the early years of the twenty-first century, the global temperature experienced an increase of temperature as **0.76** $\pm$ **.190 °C** per year over this period (Houghton, 2009). A recent study on the global warming and its impact on the Sundarbans mangrove ecosystem, India has revealed that the elevated temperature, having a range of **6.14%** (western sector) to **6.12%** (eastern sector) of this coastal environment over the past **27** years, at a rate of increase of **0.05 °C/year** have caused a lot of deleterious effects on the flora and fauna through different seasons of this long-term study period (Mitra et al. 2009).

Global warming might influence the salinity of oceanic waters in two very different ways. **First**, evaporation is triggered for an abrupt increase especially in the open sea, which in turn the salinity. **Second**, continuous seeping of freshwater from the melting of glaciers, precipitation and subsequent runoff into the estuaries, and seas lower the salinity. The global warming has caused the increased and melts of glaciers, raining, and transferred more freshwater into estuarine mangrove coast (Chakraborty et al. 2014). Of the Indian Sundarbans, the western part showed a significant and continuous decrease in salinity (**1.67 psu/ decade**), whereas the eastern sector exhibited an increase in salt **(~6 psu over 30 years)** because of the differential flood of freshwater (Mitra et al. 2009).

5.14.1.2 Mean Sea Level Variation: An Outcome of Climate Change

Influence of precipitation and other modes of water influx and outflow from the adjoining terrestrial and aquatic systems determine the annual variation of the mean sea level which reflects a macroscale global change. Comparing the annual sea level variation a yearwise annual mean sea level has been estimated to be **3.24 mm** per year in the Ganga-Brahmaputra Delta, India, which has appeared to be significantly more than the existing records relating to the trend of average global sea level rise at the rate of **2 mm per year** (Mitra et al. 2009; Chakraborty et al. 2014).

The unprecedented rates of increase of global temperature during last five decades have exceeded the natural variability to such an extent that it has caused so many major environmental problem to global environment and also for the peoples residing throughout the length and breadth of this earth. Besides, the global warming-mediated climate changes have put considerable impact on economic and political issues (Chakraborty et al. 2014) As a major contributor for extreme, unpredictable environmental variation, global climate change also impose several threats to freshwater biodiversity (Dudgeon et al. 2006; Woodward et al. 2010). Atmospheric energy fluxes and heat exchange considerably regulate the river water temperature including thermal stratification which in turn regulates other eco-biological variables in river ecosystem (Caissie 2006).

Besides, climate change directly affects runoff by inferring into different phases of hydrological cycles mostly determined by the amount and intensity of precipitation. Intensive and incessant rainfall accelerate the rate of movement of surface runoff which is directly linked up with geology, topography, soil type, and plants assemblages which together act as pathways by which precipitation reaches the river channel (Poff et al. 1997, Poff and Zimmerman, 2010). Riverine ecosystems are very much prone to the climate change mediated ecological consequences because of the followings reasons (Woodward et al. 2010): (**1**) many species within these habitats have limited dispersal abilities by which they can withstand the environment changes; (**2**) water temperatures and their fluctuations are climate-dependent; and (**3**) many systems are already exposed to many systems because of human-induced pressures. Fish and macro-invertebrates in aquatic ecosystems, being ectothermic are directly and indirectly dependent on the surrounding temperatures and thereby their past distributional patterns are thought to be determined by climate changes. Similarly, future ecological changes in the streams and rivers are also supposed to be due to the changing rates, intensity, and magnitude of the climate which will impose influences in bringing changes in the temperature changes and related consequences in the stream flows.

5.14.1.3 Role of Changes of Water Temperature on Riverine Ecology

Water temperature being the most important habitat factors in aquatic ecosystems, determine the diversity and abundances of ectothermic riverine faunal components such as fish, macro-invertebrates, etc. Water temperature in turn is determined by some pronounced ecological of factors (Caissie 2006),which can be summarized in four groups.

1. **Atmospheric conditions:** heat exchange processes after being governed by the atmospheric conditions occur at the air–water surface
2. **Stream discharge**: stream discharge by considerably determining the volume of water flow, affect the heating capacity
3. **Topography**: topography covering and involving different geographical setting, tend to influence the atmospheric factors.
4. **Stream bed**: different hyporheic processes operating at the air and water interfaces of stream bed, are controlled by some stream bed factors after being influenced by solar radiation, evaporative heat fluxes, long-wave radiation,, and convective heat transfer. Several other physical processes, such as precipitation, friction, radiation, etc. along with some other riparian vegetation, which acts as buffer against excessive heating (Caissie 2006).

Consequently, smaller rivers exhibit faster and more extreme temperature dynamics because of the vulnerability of temperature regime against heating and cooling due to lower thermal capacity. Water temperature plays a vital role in controlling almost all kind of chemo–physical–biological reactions with ectotherm aquatic organisms and thereby imparts a strong effect either on directly and indirectly in determining the magnitude of life processes in aquatic life (Woodward et al. 2010).

5.14.1.4 Impacts of Climate Change: Ecological Processes

Riverine ecosystems being one of the sensitive ecozones of the world are very much responsive to climate change because of their direct linkages with the hydrological cycle, and on atmospheric thermal regimes, after sustaining the continuous stresses generated out of the interactions between global-mediated climate change and ongoing multitudes of anthropogenic stressors (Dudgeon et al. 2006; Ormerod 2009).

5.14.1.5 Impact of Climate Change on Amount and Variability of Runoff

Human activities can alter global patterns of precipitation and the hydrologic cycle in unpredictable ways. As warming of earth in response to increases of greenhouse gases (primarily $\mathbf{CO_2}$), triggers irregularities and variabilities in evaporation and precipitation which will change and influence local weather patterns and result uncertainty the atmospheric and meteorological conditions. Because freshwater habitats are influenced greatly by the balance between precipitation and evapotranspiration, predicting the impacts of the greenhouse effect and global change on specific habitats is complicated. The strongest effects will likely occur in areas that are currently arid or where precipitation is equal to or less than potential evapotranspiration (Schaake 1990).

Predicting the amount of runoff as a function of precipitation is difficult enough when we assume that conditions are similar over the long run (when past trends can be used to predict the future). With global climate change, earth has been shifting to the states that where not necessarily common previously and forcing the human beings to live in a "**no analog**" hydrologic world (Milly et al. 2008). On the whole, a warmer world means a more active (energetic) hydrologic cycle, so the total amount of precipitation falling should increase, as should the total amount of cloud cover. However, clouds and snow can amplify back radiation of heat, making modeling difficult. A more active hydrologic cycle tends to create variance that can make predictions more difficult.

5.14.1.6 Impact of Climate Change from Molecules to Ecosystem

Global warming vis-à-vis climate change is not an alteration of temperature profiles in the atmosphere leading to the melting of glaciers and rising of sea level but should be considered as the occurrence of chain of reactions jeopardizing the basic fabric of ecosystem functioning, especially in the aquatic systems by increasing the frequency of hydro–geo–bio–chemical–physical–meteorological events. Unpredictable occurrences of different natural disasters (flood, tropical cyclones, etc.) are being increased by sea surface temperature **(S.S.T.)** rising. The increasing trend of the occurrence of natural disasters with higher frequency, intensity and magnitudes are caused by the rise in sea surface temperature. Temperature being one of the major physical factors also determines distribution, abundance, and survival of species.

Thermal adaptation is largely dependent on the physiology. Cells initially on getting the heat shock by means of prolonged and increased exposure of exposure temperature trigger the expression of heat shock genes and thereby suppress the expression of "**house-keeping**" genes.

On getting continued exposure to elevated temperature within tolerance range, cells adapt and display gene expression closer to normal, a state called "**General Adaptation Syndrome**." This is one of the important adaptive responses to changes in the ambient temperature and contributes to cell's homeostasis under different condition. A case study on mangrove–estuarine complex of Sundarbans, India, has highlighted the prospective physico–biogeochemical changes in that ecosystem in view of global warming by ground survey, reviewing of existing literatures, applicability of molecular markers and usages of remote sensing techniques. The global warming-mediated sea level rise (**SLR**) has imparted considerable impact on the biogeography and species richness of flora and fauna, salinity invasion, decreasing

pH and dissolved oxygen, unpredictable availability of nutrients, sudden occurrences with higher intensity of tropical cyclones and other related environmental consequences, increased erosion, unwanted accretion, higher sedimentation, turbidity, and decreasing biological productivity in different parts of mangrove ecosystem of experiencing Sundarbans, Indian seasonal and spatial variability. Two approaches- one at molecular level by estimating biochemical markers, heat shock proteins (**HSPs**) has revealed that although **HSP** is highly thermal tolerant (Volemmy 1992), it exhibited variability in respect of structure and function in different degrees of temperature stresses (Chakraborty et al. 2014).

5.14.1.7 Impacts of Climate Change in Conjunction of Other Environmental Perturbations on Thermal Regimes of Rivers

An increase in air temperature will dissipate to the surface of water bodies (rivers and streams) and put an imprint on it to make it warmer. Such change in thermal characteristics of riverine water leads to alter ecological processes within river ecosystem. This mode of ecological changes (warming in rivers and streams) has been reported by the data of over the past **30** years studies from global to regional scales (Webb and Nobilis 1995; Kaushal et al. 2010; Orr et al. 2014). Climate change should not be considered as the only reason for this warming of riverine water as because. Human-induced pressures such as construction of dams and dykes for river flow regulation, digging of impoundment, mining of sands, water abstraction for industries and agriculture, discharges of wastewater, change in land use especially deforestation, etc. cause temporal trends of changes in thermal regimes.

5.14.1.8 Climatic Aspects in Hydrology

Despite the consistent hydrological changes in some regions, e.g. reduced and enhanced land runoffs during summer and monsoon respectively due to higher rainfall, there exists considerable uncertainty with regard to the mode of impacts of climate change on river hydrology. In tropical country like India, already dry regions (Rajasthan, Madhya Pradesh, Gujrat, Jharkhand, etc.) will become drier, and already wet regions such as different states in the eastern India will experience the problems like flood. However, patterns and trends of stream flow trends needs proper interpretations emphasizing upon confounding factors, such as land use changes, irrigation, and urbanization.

Future trend of impact of climate conditions on catchment depend on the sensitivity of the catchment in response to change in climatic characteristics mostly depending on the change of precipitation, temperature, and evaporation. Catchment sensitivity is a function of the ratio between runoff and precipitation. Accordingly, a small ratio indicates a higher importance of precipitation for runoff. Hydrology by means of different natural or man-induced processes like flood act as prime is a driver of, and disturbances to aquatic communities, and impose regulatory impacts on structuring and functioning of the overall biodiversity in aquatic ecosystems. Animal species inhabiting in the riverine ecosystem have evolved suitable adaptive strategies in order to adjust different phases of their life cycles to seasonal variability of hydrological regimes at different eco-regions of the world. As, for example, higher growth rates of larvae are exhibited by the larval stages of benthic invertebrates during winter experiencing reduced hydraulic stress during low-flow periods in alpine rivers. Unstable environments favor the growth and proliferation of small-sized animals having short life cycles, whereas large-sized animals with longer life spans face difficulties to sustain the similar conditions (Townsend and Hildrew 1994).

5.14.1.9 Climate Change Impacts in Riverine Ecosystems

Changing land uses with more deforestation coupled with urbanization have considerably resulted depletion of groundwater reserves by obstructing the groundwater recharging processes and simultaneously pave the ways for increasing the flood hazards with a long-lasting negative effects on river hydrology. Furthermore, agricultural practices are strongly related to the climatic conditions. Thus, agricultural land use will be of particular importance for the integrity of freshwater systems in the future as intensive irrigation shares around **90%** of global water consumption which severely develop constrains on the availability of freshwater for humans and ecosystems (Bates et al., 2008).

5.14.1.10 Climate Can Induce Change in Human Uses or Directly Interact with Human

Several human-mediated developmental activities on rivers such as hydropower generation through the construction of hydropower plants through damming and building of massive built structures, water abstractions of water for irrigation, and hydropeaking, destruct the habitats of aquatic organisms through the alteration of flows of rivers, fragmentation of river channels, and disruptions of discharge regimes in both short- and longtime scales (Poff and Zimmerman 2010).

Additionally, climate change by altering and shifting the seasonal and annual stream flows, and increasing variability (including floods and droughts) within stream flow, accelerating and enhancing the rate of evaporation from reservoirs and changing sediment fluxes affect hydropower generation considerably and caused so many negative effects on hydropower generation such as damaging of run-of-the-river power plants. Simultaneously, water quality of the rivers also undergo undesirable changes as increased water temperatures cause disruption and modification of the normal biogeochemical processes involving many essential chemical elements including the self-purification process of water. Alongside, rising global temperatures certainly enhance the water requirements not only for the growth and sustenance of flora and fauna but also for the human beings to meet up their demands in tune with the changing socioeconomic systems like more usage of water for modern technology-based agriculture or cooling systems.

5.14.1.11 Climate Change and Variability in Indian Context

Climate change and variability have emerged as the most important environmental challenges. The recently released Fourth Assessment Report of the Intergovernmental Panel on Climate Change (**IPCC**) concludes that anthropogenic warming has already caused discernible influence on many physical systems, including changes in snow, ice, and glaciers. Himalayan glaciers are melting at a faster rate than before and many of them have significantly shrunk in the last few decades (Cruz et al. 2007).

Future changes in the South Asian climates will have significant impacts on water supply and demand, and eventually will have profound effects on various economic sectors and the livelihoods of millions of people. The melting of the Himalayan glaciers is projected to increase water supply within the next two to three decades, but in the long run, water supply will decrease due to the recession of the glaciers. Freshwater availability in South Asia is also projected to decrease due to climate change although monsoon precipitation will increase (Cruz et al. 2007).

5.14.1.12 Ecological Impacts of Thermal Regimes on Aquatic Fauna

Climate change by disrupting various ecosystem processes pertaining to the living condition of aquatic life, impose pervasive impact on the thermal regime (mean, minima, and maxima), for warming the water and thereby directly hamper the successful survivability of aquatic life (Fig. 4.9). Almost all fishes and macro-invertebrates being obligate poikilotherms or thermal conformers are confronted with problems in maintaining normal physiological functioning from the eggs to the adult individual because of the elevated temperature of the surrounding water (Brett 1956). Five prime types of enhanced temperature mediated effects on fishes have been outlined by Fry (1947) which also applicable to the eco-biology of aquatic macro-invertebrates too. These categories are as follows:

1. Disruption of regulatory powers of metabolic and developmental rates.
2. Limiting different behavioral activities related to feeding, reproduction, movement, and distribution,
3. Directing the stimulating response on orientation of organisms towards life-support systems
4. Masking in order to block or affect the expression to other environmental factors
5. Imposing lethal effects which directly or indirectly kill the organism to develop stress effect

Therefore, the aquatic fauna exhibit responses to water temperature changes at different levels of their hierarchical organization starting from the molecules to the biotic community via the organismal and population levels (McCullough et al. 1979; Margnuson and DeStasio, 1997; Woodward et al. 2010). At the molecular level, the ability of thermal tolerance of an organism due to its eco-physiological adaptability which is derived from the molecular make up, i.e., genetic constitution and other organism. Different biological reactions impacting on the molecular level include changes in the heat shock proteins, responses against the imposed stresses, and alterations in the functioning of enzymes and disordering of biomolecules. Besides, the thermal stress-induced physiological responses of an organism are influenced by other biological and ecological attributes such as biomass, size, sex, and seasonal variability of water quality parameters. According to Margnuson and DeStasio (1997), three different thermal guilds have been identified among the aquatic organisms in relation to the thermal regimes:

1. Cold-water species with physiological optimums **<20 °C**
2. Cold-water species having their physiological optimums between **20** and **28 °C**
3. Warm-water species with an optimum temperature **> 28 °C**. Fishes being exothermic animals are able to react behaviorally to stay within the range of their thermal tolerance and to avoid stress effects or sublethal effects by movement to find out thermally suitable microhabitats (McCullough et al. 2009).

In contrast, macro-invertebrates not having the ability of directional movements within flowing water, find out alternative option to become meiobenthic fauna utilizing the interstitial spaces as their habitats within the bottom substrate or to drift by passive movement downstream to get thermally conducive microhabitats. Responses of species to thermal variability at the population level result spatial distributions of the species in order to maintain the viability of population including abundance, productivity, and genetic diversity. Temporal movements in search of suitable and adequate microhabitats are supposed to become insufficient to ensure survivability of the local populations.

5.14.2 Case Studies on the Impact of Climate Change on Water Bodies and Its Fauna

Climate change disrupts the existing seasonal variability of water parameters of both flowing (lotic) and stagnant (lentic) aquatic ecosystems which in turn alter the mixing and stratification patterns of the aquatic ecosystem and ultimately lead to increase the probability of anoxia in cooler, deepwater habitats. All these changes result disruption of ecosystem stability and normal functioning causing losses of biodiversity in freshwater habitats (Xenopoulos et al., 2005). Additionally, slight oscillation of the average water temperatures considerably influence the growth rate, sizes, and fecundity of most of the aquatic faunal components and even in some cases such impacts reach to sublethal levels to become more acute and serious. In many mayflies, an important group of aquatic insects, warming of water temperatures just **2–3 °C** above optimal level greatly impair the reproductive potential of the females which lay a least number of eggs with an implication of maintaining future mayfly populations, predatory roles of fish, and overall ecosystem health (Vannote and Sweeney 1980; Firth and Fisher 1992).

5.14.3 Climate Change and Distribution of Riverine Fauna

Local, regional and global distribution of aquatic organisms in different have been very much determined by the climate change mediated different environmental consequences (Reyjol et al. 2007). Climate change-induced warming of surface water result a shifts of distribution of cold-water species towards the downstream end of the river to enable an upstream movement of fish from the warmer downstream into cooler areas. Even the fish species inhabiting at more downstream get the scopes to track their thermal niche into upstream reaches (Filpe et al. 2013). Comte and Grenouillet (2015) unfolded some interesting facts pertaining of such driving influence of climate change on riverine fish fauna which are unable to keep pace with the speed of the resultant ecological consequences pertaining to the higher rates for habitat losses than habitat gains (Isaak and Rieman 2013). Macro-invertebrates, mostly different groups of aquatic insects, usually overcome the problem of migration barriers by adopting overland (aerial) dispersal by their adult aquatic forms equipped with wings for their movements.

Responses of biotic communities against temperature changes are taken place via food web dynamics through the biotic interactions among different taxa, along with the roles of exotic species, diseases, and parasites (Dudgeon et al. 2006). The migration and transition of fish species along the river continuum result two trends:

1. Increase of species richness and biomass fish in the downstream
2. Turnover in species composition is evident from salmonid to cyprinid communities

Vulnerabilities of aquatic organisms to cope up with the changing temperature profiles require the involvement of different other ecological attributes such as endemism, preference for seasonality, duration of emergence period, extent of ecological niches in respect of feeding types influencing the species-specific sensitivity etc., and all these information have been generated based on the studies on the reactions of European Trichoptera fauna to climate change (Hering et al. 2009).

5.14.4 Climate Change: Adaptation and Restoration

Successful climate change adaptation requires responses at the appropriate temporal and spatial scales. Sustenance of aquatic ecosystem against the adverse effects of climate change through conservation and restoration measures requires the inter- and transdisciplinary approaches by the practitioners and researchers who are required to share information effectively with appropriate and diverse audiences such as policy- and decision-makers, **NGOs**, and other stakeholders in order to ensure and enable proactive management (Seavy et al. 2011). Adaptation of rivers to withstand the impacts of climate involves the enhancement of resilience, connectivity, and legal protection while reducing stressors, such as habitat degradation or fragmentation (Palmer et al. 2008). Riparian vegetation helps the moderation of water, maintenance of ambient air temperature by evapotranspiration, and inhibition of penetration of solar energy input by shading and thereby creates a buffer zone for filtering the sediments and nutrients, providing of foods, and shelter for many animal fauna (Richardson et al. 2007; Bond et al. 2015). Rates of evapotranspirations are always recorded maximum in forest habitats due to their high leaf area index (Tabacchi et al. 1996). Another facet of climate change adaptation is habitat connectivity which enables the moving species to find out their preferred thermal niche in their river network.

5.14.5 Impact of Climate Change on River Ecosystem Management

Rivers have been experiencing human-induced several stresses during the last couple of centuries which have been aggravated by a multitude of harmful effects of climate change (Hohensinner et al. 2011). Long-term monitoring of biological quality in rivers for different ecological changes induced by climate change is the need of the hour that will better inform future management decisions.

5.14.6 Climate Change and Water Resources

There is now consensus among scientists that human-induced climate change is warming the planet (Intergovernmental Panel on Climate Change (IPCC) 2007), although some of the details remain uncertain. The earth's warming climate is expected to negatively affect the quality and quantity of freshwater resources. Along with direct effects of warming temperatures, climate models forecast changes in regional precipitation patterns and overall higher variability in precipitation that will lead to increased frequency, magnitude, and unpredictability of flooding and droughts in many regions. Global warming will also result in untimely melting of snow pack, altering considerably in the seasonal hydrology of receiving rivers and streams which will in turn lead to the decrease of freshwater availability in many lotic ecozones by the combined actions of lack of precipitation, increased evaporation and large-scale water abstractions which by reducing the volumes of water increase the concentration of pollutants (Whitehead et al. 2009).

Warming of surface water impose both additive and synergistic effects involving nutrient pollution and the spread of exotic species on the physical environment of rivers in general and their biodiversity in particular (Barnett et al. 2008; Chakraborty et al. 2014). Smaller bodies of water will be under more threats because of ongoing climate change as they have less thermal and hydrologic buffering capacity and are more susceptible to be influenced by local precipitation patterns (Heino et al. 2009).

5.14.7 Implications of Climate Change in South Asia on the Interlinking Project of India

Rivers India, a country with alarmingly high population growth, agriculture expansion and rapid industrialization. Prompting migration of people from villages to cities is going to face severe water scarcity in the coming decades. The river's interlinking project is with plan to bring an additional **34** million hectares (**Mha**) of land under irrigation using **173** billion cubic meters (**BCM**), but such efforts concerning with river diversion would certainly disturb the entire hydrological cycle by hindering normal ecological functioning of all those rivers (Gurjar 2003; Radhakrishna 2003). This has necessitated to undertake a multidisciplinary considerations on hydrological, environmental, agricultural, socioeconomic, and political components giving more emphasis on people's perception and opinions towards comprehensive assessment of the feasibility, desirability, and viability of the river interlinking project. It is not enough to merely transfer a quantum of water through different link canals from one point to another.

Different scientific evidences have highlighted that ongoing climate change will pose serious challenges to the people of South Asia because of the addition of huge amount of greenhouse gases to add complex impacts affecting every sector of society, especially the nation's water resources, (IPCC 2001; Lal et al. 2011). In such context, it can be summerized that the nature of expected climate change, in the context of the environmental problems of India, is likely to be such that:

1. All India mean water surface temperatures keeping pace with global average will continue to increase above the historical levels.
2. The regional and seasonal pattern of temperature varies across the country.
3. The continuous accumulation and increase of the greenhouse gas concentrations in the atmosphere result an increase of global average precipitation and also modify the pattern, intensity, and duration of precipitation.
4. Climate change will enhance the frequency and intensity of the heavy precipitation events in India (high confidence); changes in cyclone frequency and other such natural disasters.
5. Higher sea levels associated with thermal expansion and elevation are expected to push sea water further inland in rivers, deltas, etc. which will certainly adversely affect the quality and quantity of freshwater supplies in several coastal fronts of India.

6. The annual surface flow in Himalayan river basins is projected to increase due to climate change resulting in enhanced probability of floods in this region.
7. Increasing $\mathbf{CO_2}$ concentrations will increase plant growth which in turn leads to increase transpiring tissue and transpiration alongside decreasing of runoff.
8. Climate change in India has resulted a shift in species distributions northward, with the more possibilities of extinctions of temperate species at lower latitudes, and range expansion of warm-water species into northern latitudes in India.
9. India, a very highly populated country, must take some proper pro-environmental steps in order to undertake sustainable water management such as recycling and reuse of wastewater, rainwater harvesting and groundwater recharge, proper planning for both intra- and inter-basin transfer of water in a stepwise manner and based on priorities and needs of the available water resources.
10. The priority of action, however, must be by renovation of existing structures and reuse of wastewater and then inter-basin transfers (hydropower, inland navigation) giving due priorities of complex political, technological, and financial requirements of the country.

5.15 Point and Non-point Sources of Pollution: Entry Path and Roles of Environmental Variables

The widespread entry paths of harmful pollutants (Tables 5.2, 5.3, 5.4, 5.5, 5.6, 5.7, 5.8, and 5.9) can be classified as point sources and non-point sources which are determined by several physicochemical processes and properties such as solubility, lipophilicity, vapor pressure **pH**, temperature, ultraviolet radiation, soil type, etc. on the environmental context of the river. Pollutants having high water solubility and vapor pressure such as nitrogenous fertilizers, pesticides, etc. enter aquatic systems usually via drainage/steam discharge, runoff, subsurface flows, whereas compounds with a low water solubility and low vapor pressure (polychlorinated biphenyls) mostly enter aquatic systems by wet deposition from the atmosphere. In contrast, compounds with a low water solubility but high vapor pressure (pyrethroid insecticides) can get access to the aquatic systems primarily adsorbed or bound to particulate matter, utilizing the runoff events.

In addition, the prevailing environmental status of all biogeographic zones also, influences the movement and, mode of degradation and bio-availability of organic compounds. A number of ecological variables such as currents, density, pH, temperature, ionic composition, etc. of water govern the speciation of metals and their subsequent eco-toxicological effects.

Table 5.4 Some studies into the effects of deforestation on water quantity

Countries/Regions	Sources	Comments
Europe		
UK: Plantation forest, Plynlimon	Roberts and Crane (1997)	Longitudinal study
Belgium	Bulrot et al. (1990)	Model study
France: Mediterranean pine	Lavabre et al. (1993)	Longitudinal study: Fire
Israel: Mediterranean woodland	Inbar et al. (1998)	Longitudinal study: Fire
North America		
Pacific Northwest: Oregon	Jones and Grant (1996)	Paired catchments
Pacific Northwest: Columbia River	Matheussen et al. (2000)	Model study
Northwest California	Wright et al. (1990)	Paired catchments
Colorado	Troendle and Reuss (1997)	Paired catchments
California pine	Keller et al. (1997)	Longitudinal study: Fire
Tropical forest		
Malaysia	Malmer (1996)	Paired catchments
Indonesia	Asdak et al. (1998b)	Paired catchments
Nigeria	Lal (1996)	Longitudinal study
Subtropical forest and woodland		
Lake Malawi catchment	Calder et al. (1995)	Model study
South Africa	Scott (1997)	Paired catchments
Southeast Australia	Croke et al. (1999)	Paired catchments
Western Australia	Bari et al. (1996)	Paired catchments

5.16 Role of Geo-Hydrological Factors on Pollutants's Behavior

Catchment hydrology, a determinant of the chemical exposure regime based on the timing, frequency, magnitude, and duration of water flows within the lateral and longitudinal connectivity of rivers also regulate the concentration, transport, and mode action of several pollutants in rivers. While the discharge minima are associated with the highest chemical concentrations from point sources, the discharge maxima are very much influenced by heavy precipitation which induce surface runoff and subsurface drainage leading to the diffuse entry of many agrochemicals including pesticides and chemical fertilizer derived nutrients, chemicals coming out from the anthropogenic activities [biocides, metals, nanomaterials, and polycyclic aromatic hydrocarbons (**PAHs**)]. Reaching of such chemical pollutants to the river ecosystems may be of two ways: first, intentional (pesticide spraying) and second, unintentional (leaching or gassing out) Different paths and ways of the movement and distribution of all those pollutants are facilitated by on geological, hydrological, climatic, and land-use patterns, in the river's catchment. Different sources and pathways of water pollutants can be summarized by Wittmer et al. 2010 in the following manners:

Table 5.5 Water-mediated human disease-causing organisms

Group	Organisms	Disease/Symptoms
Bacteria	*Salmonella* spp.	Typhoid fever, paratyphoid fever, gastroenteritis
	Shigella spp.	Gastroenteritis-dysentery
	Vibrio cholerae	Cholera
	Escherichia coli	Gastroenteritis
	Leptospira icterohaemorrhagiae	Weil's disease
	*Campylobacte*r spp.	Gastroenteritis
	Yersinia enterocolitica	Gastroenteritis
	Mycobacterium spp.	Tuberculosis/respiratory illness
	Legionella pneumophila	Legionnaire's disease/acute respiratory illness
Virus	Hepatitis A	Liver disease
	Norwalk agent, rotaviruses, astroviruses	Gastroenteritis
	Poliovirus	Polio
	Coxsackievirus	Herpangina/meningitis, respiratory illness, paralysis, fever
	Enteroviruses (68–71)	Pleurodynia/meningitis, pericarditis, myocarditis
Protozoa	*Giardia lamblia*	Diarrhea, abdominal pains, nausea, fatigue, weight loss
	Entamoeba histolytica	Acute dysentery
	Acanthamoeba castellanii, *Naegleria* spp.	Meningoencephalitis
	Balantidium coli	Dysentery
	Cryptosporidium spp.	Dysentery
Helminths	Nematodes (*Ascaris lumbricoides*, *Trichuris trichiura*)	Intestinal obstruction in children
	Hookworms (*Necator americanus*, *Ancylostoma duodenale*)	Hookworm disease/gastrointestinal tract
	Tapeworms (*Taenia* spp.)	Abdominal discomfort, hunger pains
	Schistosoma mansoni	Schistosomiasis (liver, bladder, and large intestine)

Source: Bitton (1994)

1. Direct industrial discharge, emission, deposition and releasing from mining activities, and from the effluents from wastewater treatment plants (**WWTPs**)
2. Runoff with erosion products from the land surface and subsurface flows after precipitation
3. Disposal of wastes, leading to the resuspension, desorption, or diffusion of chemicals into the water phase
4. Atmospheric deposition of chemicals and also from the accidental spills

Table 5.6 Toxic effects of some commonly used chemicals on the biological components of river ecosystem

Sources and applicabilities of chemicals	Nature of chemicals or chemical group	Effects on structure or functions	Sources
Pyrolysis (incomplete combustion) of organic material	Polycyclic aromatic hydrocarbons (PAH)	Genotoxicity and embryotoxicity and changes in metabolism of fish in Chinese rivers	Floehr et al. (2015)
Pharmaceuticals	Antibiotics	Higher antibiotic resistance genes in US river sediments with high concentrations of antibiotics	Pei et al. (2006)
Synthetic hormones and additives	17a-Ethynylestradiol, nonylphenol	Highest feminization of fish in surface waters in the Netherlands with highest potential exposure to endocrine-disrupting chemicals	Vethaak et al. (2005)
Sunscreen UV filters	3-Benzylidene camphor	Environmental concentrations related to histological and reproductive effects in fish under laboratory conditions	Fent et al. (2008)
Agricultural pesticides	Insecticides and fungicides	Pesticide toxicity associated with changes in microbial and invertebrate communities and reduction in organic matter processing in Australian streams	Schäfer (2012)
Biocides in consumer products	Triclosan	Changes in microbial communities in US streams	Drury et al. (2013)
Mining and geogenic background	Metals	Changes in invertebrate communities in US mountain streams	Clements et al. (2000)
Salts related to mining and road de-icing	Chloride	Changes in mortality and reproduction of aquatic plants and animals	Cañedo-Argüelles et al. (2013)
Fuel combustion and geogenic background	Acids	Reduction in organic matter processing and loss of sensitive invertebrate species in acidic streams	Pye et al. (2012)
Coolants, plasticizers, and insulting fluids	Polychlorinated biphenyls and other organochlorines	Reduced gonad size, decreased plasma levels of 11-ketotestosterone, EROD and vitellogenin induction, and histopathologies of male gonads	Randak et al. (2009)
Municipal wastewater	Complex mixture of micropollutants	Reduced feeding of invertebrates and leaf litter decomposition	Englert et al. (2013)
Road runoff	Metals and polyaromatic hydrocarbons	Changes in invertebrate communities and organic matter processing	Maltby et al. (1995)

Table 5.7 Point sources and the expected contamination of groundwater

Source	Inorganic contaminants	Organic contaminants
Urban areas	Heavy metals and salts	Oil products, biodegradable organics
Industrial sites	Heavy metals	Chlorinated hydrocarbons, hydrocarbons, oil products
Landfills	Salts and heavy metals	Biodegradable organic xenobiotics
Mining disposal sites	Heavy metals, salts and arsenics	Xenobiotics
Dredged sediment and sludge disposal	Heavy metals	Xenobiotics
Hazardous waste sites	Heavy metals (concentrated)	Concentrated xenobiotics
Leaking storage tanks	–	Oil products (petrol)
Line sources (motorways, railways, sewerage system etc.)	Heavy metals, salts	Oil products, pesticides

Table 5.8 Major sources and causes of water quality deterioration

Effluents	Factors affecting water quality deterioration
Domestic sewage	BOD, suspended solids, ammonia, nitrate, phosphate
Vegetable processing	BOD, suspended solids, color
Chemical industry	BOD, ammonia, phenols, non-biodegradable organics, heat
Iron and steel manufacturer	Cyanides, phenols, thiocyanate, pH, ammonia, sulfides
Coal mining	Suspended solids, Iron, pH, dissolve solids
Metal finishing	Cyanide, copper, cadmium, nickel, pH
Brewing	Suspended solids, BOD, pH
Dairy products	BOD, pH
Oil refineries	Heat, ammonia, phenols, oil, sulfide
Quarrying	Suspended solids, oil
Power generation	Heat

5.17 Toxic Persistent Pollutants in River Ecosystem

5.17.1 Eco-toxicological Processes for Persistent Toxic Pollutants

Toxic substances have the tremendous potential for causing short or long-term damage to human health and the environment by way of their ingestion, inhalation, or direct consumption. In the natural aquatic environment, two major toxic substances. [Toxic organic chemicals (**TOCs**) and heavy metals] are found. In the surface water of riverine ecosystem, several toxic substances, such as metals,

Table 5.9 Intensity of sand mining at a particular site (Gopiballavpur) in the river bed of Subarnarekha River, Midnapore (West), West Bengal, India

Site	Right side of Subarnarekha (near Nayabasan)	Left side of Subarnarekha (near Bridge)
Area of mining (m^2)	522,500 (950 × 550)	300,000 (1200 × 250)
No. of mining stations (khadan) with in this area	5	5
Mode of mining	Machine and manual	Machine and manual
Avg. mining intensity	300 tract/day (300 septic)	225 track/day
No. of laborers	300	200
Avg. earning by a laborer/day (Rs.)	250	
Govt. get/ khadan for 5 year (Rs.)	15,000	
Rate of sand (Rs./track)	300 (for 300 septic) and 400 (for 400 septic)	
Labor charge for loading /track (Rs.)	800 (cost for labor for 300 septic) and 1100 (cost for labor for 400 septic)	

PAHs, PCBs, and pesticides, are encountered. These substances enter waterways through municipal and industrial discharges; runoffs from the drainage basins, adjoining agriculture fields, etc. and also from deposition from the atmosphere. Many toxic contaminants have been found to be deposited in the bottom sediments which are forced to float and resuspend into the water columns by currents, wind, and waves of water. Drifting of atmospheric pollutants after being deposited in water bodies also contribute to water contamination. Toxic substances in a water body can exist in two basic forms: the dissolved form (transported with water flows) and the particulate form (transported with sediments). The former in the dissolved phase cause more harm to the environment. Than the latter. Two distinct eco-toxicological phenomena are bioaccumulation and bio-magnification, which do not pertain to many conventional pollutants, such as nitrogen and phosphorus. Bioaccumulation, a eco-biological t process which enables some persistent contaminants to build up their concentration and also to accumulate in the body tissues of organisms when they travel from one trophic level to next via digestive processes to higher levels of the food chain.

Bio-magnification is the magnification of the concentration and intensity of persistent and non-degradable pollutants in the biota at each successive trophic levels in a food chain. The concentration of contaminants progressively increases from the bottom of the food chain (phytoplankton and zooplankton) to the top of the food chain (fish-eating birds) through repeated eating and being eaten phenomenon. Bioaccumulation is the building up of a toxic substance by aquatic organisms to concentration levels much higher than the surrounding environment. Building up of toxicants within the bodies of organism by the bioaccumulation process is primarily due to the uptake and retention of a chemical by living organisms, as a result of direct contact with, or eating contaminated food or drinking contaminated water. For example, the predator's tissues could become contaminated on eating a large number of prey, with each having a small amount of a pollutant in its body. Through this bio-magnification process, toxic substances tend to travel through the food web and become more concentrated in the faunal components belonging to higher trophic levels in the food chain. In this way, certain chemicals, such as mercury, **PCBs**, and some pesticides, can become concentrated from very low levels in the water to toxic levels in the bodies of animals such as birds, reptiles, and even to human beings. Toxic contaminants can threaten human and ecological health either directly or through bioaccumulation and bio-magnification processes through the food chains and food web dynamics of the riverine ecosystem.

5.17.2 Toxic Organic Chemicals (TOCs): Sources and Background

Toxic organic chemicals (**TOC**s) are synthetic compounds having carbon as its structural entities. These **TOC**s not only persist in the environment but also experience bioaccumulation and bio-magnification in the food web. The **TOC**s can be categorized based on their usage and chemical classes (CEQ 1978). Toxic organic chemicals that are frequently cited as causing environmental damage mostly belong to four major categories such as (**1**) **PCB**s, (**2**) **PAHs**, (**3**) pesticides, and (**4**) dioxins and furans. These **TOC**s tend to persist and accumulate in the environment and do not undergo breakdown in natural ecosystems. Some of the toxic **TOCs,** such as **DDT** and **PCBs**, have been banned for their use in the **USA** for decades yet continue to cause environmental problems.

It is well documented, for example, that **DDT** built up through the levels of the food chain and caused severe damage to the ecosystem.

1. The **PCBs** are a group of banned synthetic organic chemicals that were manufactured as coolants and lubricants for electrical equipment, until they were banned in the **1970**s. They are resistant to biological and chemical degradation and can persist in the environment for decades. Problems associated with **PCBs** include cancer, fertility problems, and nervous system impairment.
2. The **PAHs** are a complex mix of organic compounds, including fossil fuels and their combustion. They are commonly the by-products of oil burning. Exposure generally occurs by breathing smoke or exhaust from automobiles or other combustion processes. They can cause breathing difficulties and are carcinogenic. Many **PAHs** can be broken down over a period of weeks or months by microorganisms.
3. Pesticides being one of the major categories of toxic substances are chemicals used to control or eliminate undesirable organisms, such as insects, fungi, or others that may reduce crop yields or impact the health of livestock. Many of them breakdown into non-toxic chemicals within a few days of application.

Some pesticides are refractory and can build up in sediments or bioaccumulate in food chains, posing potential threats to human health and biodiversity including wildlife. For example, **DDT** is a highly toxic poison that is capable of killing many different species dioxins and furans are families of chemicals that are emitted as an outcome of incombustion and emission processes which have already been estimated as severely toxic to both humans and wildlife.

These by-products are formed in two major ways:

1. During burning of these materials at low temperatures
2. During the manufacturing processes of some products. Once they have entered the environment, dioxins and furans can persist for a long time. Instead, most of these reach to the non-target sectors of agro-ecosystems and/or spreads to surrounding ecosystems as chemical pollutants

Most investigations of pesticide effects on the environment have focused either on populations of non-target species or on the degree of contamination of land, water, and air (Pimentel 1961; Pimentel et al. 1997, 2004; Edwards & Thompson 1973; Edwards 1973a, b; Brown and Peet 2003; Brown et al. 1998). Almost no information exists on the effects of pesticides on whole ecosystem dynamics of an entire ecosystem including species diversity, ecosystem stability, food chains, energy flow, nutrient cycling, genetics of organisms, and physical resources.

5.17.3 Ecosystem Stability and Resilience: Impact of Pesticides

5.17.3.1 Effect of Pesticides on Ecosystem

The harmful impacts of persistent pesticides are dependent on three of their physical–chemical properties: (**1**) their tendency to get dissolved in water and other solvents; (**2**) their ability to get vaporized; and (**3**) their power of resistance against different modes of decomposition processes. Pesticides may influence populations of organisms and consequently affect interactions among species within ecosystems, or they may change the stability of these systems. The best documented examples of such effects are from agro-ecosystems. After using insecticides on tropical cotton crops, the two or three important pests of the crop were controlled that greatly increased yields, but within a few seasons, the chemicals after reducing the populations of natural enemies provide the scope of a number of other arthropod species to become pests.

Reproduction of aquatic animals are directly affected by the toxic effect of pesticides as evidenced from the impact of non-degradable organochlorine pesticides on reproduction of raptors and other birds causing thinning of their eggshells after severely affecting **Ca** metabolism (Keith and Gruchy, 1972; Peakall, 1975; Haegele and Tucker, 1974). Carnivorous birds, mostly living on fish, suffer to a greater extent than the terrestrial predatory birds, as the former are more susceptible to the bioaccumulation of pesticides via aquatic food chains (Pimentel 1971). Pesticides have been seen to cause deleterious effects on the reproduction in invertebrates. For example, sublethal doses of **DDT**, dieldrin, and parathion were observed to increase the rate of egg production by the Colorado potato beetles after **2** weeks of the administration of pesticides by **50%, 33%,** and **65%,** respectively (Abdallah 1968). Populations of invertebrates can recover more rapidly because of their higher growth and population densities than those of birds and mammals with slow rates of population increase.

Aquatic ecosystems with flowing water can usually recover their structure and function more quickly from pesticide effects than ponds with standing water. In general, the duration of pesticide stress from a single exposure is influenced primarily by two factors: toxicity and persistence. A chemical that is toxic to a wide range of organisms, but is short-lived, such as a fumigant, may have a major impact on exposed ecosystems (Edwards and Thompson 1973). Conversely, a very persistent pesticide that is not highly toxic to wildlife may have little effect on ecosystems. Clearly, a chemical that is both highly toxic and persistent is likely to have a major and long-lasting effect on ecosystems. However, with currently used pesticides, most ecosystems recover rapidly, in **1–5** years at most (Brown 1978). Ecosystems start to recover as soon as a pesticide stress disappears, and the time required for complete recovery depends both on the severity of the impact of the pesticide on the ecosystem.

5.17.3.2 Impact of Pesticides on Nutrients of the Ecosystem

There is less evidence for effects of pesticides on decomposer organisms in aquatic systems. However, the susceptibility of arthropods, which are the main decomposer organisms in aquatic systems, to pesticides suggests that pesticides may slow organic matter decomposition in water. Most nutrients, especially carbon, nitrogen, phosphorus, potassium, and sulfur, are taken up by plants, which in turn may be eaten by animals. These nutrients are eventually returned to the soil or atmosphere via decomposition of dead organisms. The amounts and forms of nutrients in soil and plants may be changed by pesticides affecting the dynamics of these elements in the ecosystem. Pesticides can alter the chemical makeup of plants. The changes that occur appear to be specific for both the plants and pesticides involved. For example, certain organochlorine insecticides have triggered an increase of the amounts of some macro- and microelement constituents (**N, P, K, Ca, Mg, Mn, Fe, Cu, B, Al, Sr**, and **Zn)** of corn and beans and decreased the amounts of others (Cole et al. 1968). In similar other study, pesticides such as **DDT**, aldrin, endrin, and lindane acted as the stimulants for the synthesis of some of the important amino acids such as arginine, histidine, leucine, lysine, proline, and tyrosine but simultaneously cause a decrease of the amount of tryptophan (Thakre and Saxena 1972). Sensitivity of certain microbial species to pesticides can change the speed or efficiency of cycling of nutrients. For example, the herbicide **EPTC** at normal dosages impaired the decomposition of cellulose in soil (Sobieszczanski 1968).

5.17.3.3 Susceptibility of Pesticide Impacts on Ecosystem

Ecosystems that have a rich flora and fauna and high rates of energy flow and nutrient cycling are generally complex and have a good degree of resistance to perturbations from such stresses as pesticides. Ecosystems that have such characteristics are natural forest, grassland, lake, and estuarine systems. The ecosystems that are under relatively intense stress from pesticides include two main groups: ecosystems that lack complexity and resilience, and ecosystems that regularly receive relatively large quantities of pesticides. Lake, pond, river, and stream ecosystems are frequently under pesticide stress because they receive pesticides in runoff and from drift. Systems with running water are more resilient than those where water is static, because running water flushes away pesticide pollutants. Estuarine ecosystems eventually receive much of the pesticides that have accumulated in freshwater ecosystems, as the chemicals gradually pass down streams and rivers to the estuaries (Edwards 1973b). The pesticide may also accumulate in the environment, if the life of the chemical is greater than the frequency of application. Classic examples of pesticides that persist for many years are many of the organochlorine insecticides such as **DDT** and toxaphene (Pimentel 1971).

5.17.3.4 Water Solubility of Pesticides

Pesticides with a high solubility in water, such as aldicarb insecticides and several herbicides, have a tendency to be washed from treated crop ecosystems to aquatic ecosystems (Miles and Harris 1978) or even into drinking water (Edwards 1973a). A high lipid versus water coefficient in a pesticide suggests that it may have the tendency to accumulate in living organisms. Most organisms contain lipids and, hence, are likely to take up lipophilic pesticides (such as many organochlorine insecticides) from their soil or water environments.

5.17.3.5 Eco-toxic Effects Pesticides on Biota of Ecosystem

Pesticides are biological poisons, some of which are toxic to a wide array of organisms. Of those used against pest complexes, relatively few have a narrow range of activity. The natural biota perform many essential functions for agriculture, forestry, and other aspects of human welfare, such as preventing the accumulation of organic wastes, clearing water, and soil of chemical pollutants such as pesticides, recycling vital chemical elements within the ecosystem, producing biotic nitrogen for fertilizer, buffering ecological effects of air pollutants, moderating climatic change, conserving soil and water, and protecting and conserving genetic materials for agriculture and forestry, in order to ensure the supply of their food via the harvest of fish and other wildlife (Pimentel et al. 1980). Pesticides can influence major ecological functioning by altering food chains and food webs dynamics, reducing species diversity and; changing patterns of energy flow and nutrient cycling (including nitrogen); reducing soil, water, and air quality. All these ultimately lead to result changing of the stability and resilience of ecosystems.

5.17.3.6 Impacts of Pesticides Across Levels of Biological Organization

Chemical toxic substances on entering into the aquatic ecosystem impart toxic impacts on freshwater organisms individually and also at populations, or species level. This is evident from the effects of polychlorinated biphenyls along with other organochlorine chemicals in disrupting activities of enzymes and other relevant chemical signaling inducing the formation of vitellogenin or leading to reduce plasma levels of **11-**ketotestosterone. All such physiological effects not only form the basis of changes in the metabolism and chemical signaling by reducing the fitness or mortality but also cause disturbance in the higher biological levels.

Different magnitudes of the harmful effects of endocrine-disrupting chemicals on individuals cause several eco-biological disorders such as changes in the population structure, deviation from the normal gender ratio (males to females), etc. Besides, harmful effects of different antibiotics, biocides (triclosan), and metals (copper) also result changes in the next hierarchical levels (community) and ultimately to the malfunctioning of the ecosystem. The impacts at the community level are not buffered by functional redundancy and are in turn induced by the loss of sensitive organisms, without being compensated by an increase of the tolerant organisms. At the end, an increase of ecosystem-level impacts starting from the physiological level towards the meta-ecosystem and landscape level leads to the development of macro-ecological characteristics, such as species abundance distributions. However, most of the eco-toxicological studies have restricted on focusing only on the lower levels of biological organization (Beketov and Liess 2012).

5.17.3.6.1 Effect of Pesticides on Fishes and Other River Animals: Field and Experimental Studies from India

5.17.3.6.1.1 Mode of Action of Pesticides

Pesticides after application to the agriculture fields eventually reach to the aquatic system in considerable amounts via agriculture runoff from land, contaminated ground water, and bottom sediments, urban runoff, municipal water treatment plants, industrial wastes and atmospheric fall out through rain, etc. These pesticides affect the target as well as several non-target species also.

Sufferings of fishes to pesticide may be expressed either by their mortality or by alterations in their growth, development, reproduction, biochemistry and physiology depending upon several factors like (**a**) physical and chemical properties as well the concentration of the pesticides, or their transformed by-products in water ecosystem;

(**b**) duration and kind of exposure (acute or chronic, intermittent, or continuous); and (**c**) ability of fish to metabolize the pesticide absorbed.

One of the reasons for large-scale mortality of fish and low fish landing has been attributed to the increasing concentration of pesticides in natural water bodies. In fact increasing physical, chemical, and biological factors of the aquatic ecosystem complicate the process and the response of a fish to a particular pesticide exposure.

With the accumulation in aquatic ecosystem, a good amount of pesticide undergoes breakdown and transformation depending upon physicochemical and biological factors of the water ecosystem. Simultaneously, a considerable amount of pesticides and their by-products enter the fish body, where these are distributed and metabolized depending upon the detoxifying ability of the fish, and elicit some responses in which depend on the nature and concentration in pesticide as well as the duration of their persistence in fish body. The hydrophilic pesticides are readily transported to fish then the hydrophobic ones. Water-soluble pesticides enter the fish either through the body surface or gill or mouth. Pesticides in foodstuffs get ingested and absorbed through the gastrointestinal tract. The absorption, distribution, bio-transformation and consequent eco-toxicological effects of pesticides on fish are determined by the route of entry of pesticides and duration of exposure.

5.17.3.6.1.2 Case Studies on Fate of Pesticides on Aquatic Animals

Laboratory studies on the effect of pesticides with different concentrations on fish embryos portray their greater susceptibility of pesticides. Several of the eggs of fish failed to hatch and the embryos succumbed to the toxicity at various stages of development. Decrease in the hatching of eggs of *Carpinus carpio* was recorded with increase in malathion concentration in the environment. Malathion is known to exert inhibitory mechanism in **DNA** replication during protein synthesis leading to abnormalities and death. Application of **DDT** and Aldrin even at safe levels indicated hampering of reproduction several fish species. The growth of Gastropods (Molluscs) was found to be reduced by more than **25%** under exposure to **DDT** at **0.1 ppb**, and **50%** at **0.5 ppb** concentrations. The decrease in weight was exhibited by the thinning of the shells rather than reduction in flesh weight. Although the pesticide residues studies in Indian rivers are scanty. But a number of researchers from their studies on the pesticides bioassays, bioaccumulation, and biochemical aspects have shown some results on toxic effects of pesticides.

About **2573 t** of pesticides are used in a year in the Ganga basin. Incidences and magnitude of **DDT** and **BHC-y** residues in fishes of tidal stretch of the Ganga were of higher order in the industrial zone compare to riverine and estuarine zones. Greater accumulation of **DDT** (**65–150 ppm**) was recorded in mollusks, followed by fish (**31–460 ppb**), plankton (**15–150 ppb**), and sediments (**70–80 ppb**). **BHC-y** in fish was **46–210 ppb**, in mollusks **40–86 ppb** and in sediments **21–70 ppb**. On the basis of ambient water, the bio-magnification values were **2500** in Plankton, **3600** in gastropods (mollusks), **7500** in Fish, and **15,800** in Bivalve mollusks. Among the pollution hazards from the agriculture sector, the damage caused by the pesticides is the most lethal and interminable to the environment.

The organochlorine pesticides are lipophilic, extremely toxic, and non-biodegradable which assume alarming proportions as they are proved to be biologically magnified and accumulated in fish posing serious threat to the fish-eating human populations. Most of the commonly used pesticides in India like **DDT, BHC**, endosulfan, ethyl parathion, methyl parathion, dimethoate, phosphamidon, carboryl, and **2–4-D** have been screened to evaluate their toxicity. All of them have been found to be toxic to the food organisms and fish populations.

Sublethal concentration of **DDT** and **BHC** adversely affects the fish at tissue levels. Besides a decline in growth, **RBC** count, **HB,** and **PVC** level has been noticed in *Oreochromis mossambicus* along with the damage to liver cells. Similar effects have also been noticed in *Labeo rohita and Cirrhinus mrigala.* Chlorinated hydrocarbons persisting longer time in water get accumulated progressively in different steps of food chain. Fishes like other animals are capable of concentrating lipophilic compounds in their body tissues several hundred to several thousand times of their ambient concentration in water. **DDT** can accumulate within fish to the levels of more than **10,000** times the concentration present in the environment.

Studies have been reported indicating adverse effects at structural level and at the metabolic level. Pesticides on finding their way to aquatic habitats are found to interfere with the reproductive capacity of the fishes. Distortion in testicular and ovarian histology of Tilapia has been noticed. Sublethal levels of lindane (**0.16 ppm**) and malathion (**4.0 ppm**) also induced degeneration in the ovaries, drastically reducing the reproductive potential of the fishes. **BHC** and dieldrin have been known to cause ovarian atrophy even in hardy fishes like *Heteropneustes fossilis*. Verma et al. (1983) detected bioaccumulation of endosulfan (thiodon) **126** times on the ovaries of the murrel, *Channa punctatus*, when exposed to **1 ppb**, concentration of endosulfan for **32** days. Toxicity of methyl parathion was tested on the three carp's species to ascertain its impact on the liver metabolism.

At sublethal levels, liver glycogen was reduced to the level of **50%** during the first 4 days of exposure though the level recovered during subsequent days. Several studies indicate impairment of liver functions in fishes at considerably low concentrations of pesticides in the ambient water. A survey of the industrial cities of India has shown that industrial wastewater constitutes by volume between **8%** and **16%** of the total wastewater produced, whereas the remaining **84–92%** are generated from the domestic sector.

In view of with the rapid pace of industrialization coupled with uncontrolled urbanization, the wastewater from the industrial sector is expected to rise to an alarming level in the coming decades. The problem of toxicants affecting aquatic ecosystem is complex but understanding on the mode of production, ways of drainage and disposal, and the mode of action on aquatic environment leading to the deterioration of water qualities should be monitored in order to take proper mitigation strategies to combat the problems of eco-degradation be adopted.

5.18 Metals as Toxic Pollutants in the River Ecosystem

5.18.1 Definition and Chemical Properties of Metals

A metal is defined mainly focusing on its physical properties, such as electrical conductivity, reflectivity, and strength and the element considered as to be metalloids in which more electrons are present to form a cation in water. Heavy metals usually refer to those metals which have atomic numbers in between **21** and **84**. Heavy metals pose serious toxic problems when their concentration exceeds water quality standards. Heavy metals as pollutants are more pervasive persistent in comparison to other **TOC**. Alongside the anthropogenic sources, they have natural sources from the dissolution of rocks and minerals. Heavy metals are found in the environment both as a dissolved and a particulate phase. Interchange between the particulate and the dissolved metal occurs via sorption–desorption mechanisms. The unique characteristics of heavy metals include (**1**) bioaccumulation and bio-magnification; (**2**) long decay time; (**3**) natural occurrences; (**4**) toxicity closely linked to the metal's dissolvability; and (5) many chemical forms. Most common heavy metals having toxicity potential are **Hg, Zn, Cu, Cd, Pb**, etc. As persistent pollutants, heavy metals also exhibit bioaccumulation and bio-magnification processes. Lead and mercury rank highest with respect to real or anticipated environmental hazard. The primary health impacts from mercury are on the development of the brain and nervous system. When mercury becomes deposited within a water body, it can accumulate in the tissues of fish to concentrations much higher than in the surrounding water. Mercury is the most common contaminant in fish in the United States and Canada. The decay times required for the decay of metals are considerably different from other **TOCs** which mainly depend on its structure.

Once that structure of **TOC** is destroyed, the toxic effect disappears. Metals, do not depend for their on the structure and persist indefinitely in one form or another posing a much longer threat to the environment than do **TOCs**. Several anthropogenic activities such as industrial processes, emission from automobiles, dumping of municipal wastes, mining have altered the distribution of metals in the environment. Dissolved metals, rather than particulate metals, are responsible for more toxicity to organisms. Sediments act as major facilitator of regulating dissolved concentrations in natural waters. Several ecological parameters such as **pH**, temperature, and salinity affect the metal solubility significantly. In general, metal solubility's are lower at near-neutral **pH** than in acidic or highly alkaline waters.

5.18.2 Heavy Metals and Environmental Compartments

The toxic effects of heavy metals on biological organisms have drawn considerable attention of the environmental researchers across the world because of the ecological and economic consequences (Figs. 5.11 and 5.12). The term heavy metal generally means about those metals whose atomic numbers are more than iron or possess a density greater than **5%**. Concern over metal pollution focused sharply when incidents involving the fatal poisoning of human being in some countries with mercury (**Hg**) and cadmium (**Cd**) came to light.

Mercury being a dangerous pollutant became the worst offenders resulting mass mortality of human beings in Sweden and Japan and caused the dreaded Minamata disease in Japan. The concentration of heavy metals within the sediments provides necessary inputs for determining the sources and the extent of metallic pollution in aquatic environment. The continuous monitoring of metal levels in the sediments through the estimation of their concentration in the sediments is a prerequisite in detecting their source, intensity and extent of metal pollution in the aquatic system. Different industrial effluents and domestic sewage usually remain in the water bodies as suspended materials which carry different metals and ultimately deposit measurable concentration of lead (**Pb**), zinc (**Zn**), cadmium (**Cd**), chromium (**Cr**), copper (**Cu**), nickel (**Ni**), cobalt (**Cb**), manganese (**Mn**), and iron (**Fe**).The industrial and the sewage input to the tributaries and rivers are the most likely sources of heavy metals contamination. The biological indicator organisms have been used by many workers to monitor the time, abundance of trace metals and other pollutants in the aquatic environment. It has been seen that chemical analysis of the tissues of submerges plants gave valuable information about the contamination of the surrounding water.

Heavy metal concentration in water depends mainly on the **pH** of the system. It has been reported that the precipitation of heavy metals is enhanced at **pH** above **7.0**. The concentration of heavy metals in the sediments depends on its **pH**, **CaCO3,** and organic matter. Adsorption of "**cations**" by organic matter is due to particularly to a negative charge of colloids. The increased deposition and thereby enhanced concentration of heavy metals bear direct connection with the precipitation of metallic hydroxides, carbonates and sulfides, which form the part of sediments after settling down. The composition of these settled and precipitated metallic compounds are governed by the several hydrochemical properties of the concerned water body.

The heavy metal contents in the aquatic animals originates from two routes of intake: **First**, free ions and simple compound dissolved in the water are taken up directly through the epithelium of the skins, gills, and alimentary canal; **second**, having been accumulated in food organisms, the heavy metals are incorporated within the bodies through nutrition. The metals from the aquatic environments are generally taken up into the human body via gastrointestinal tract through drinking water and food. Heavy metal pollution of rivers is mostly caused by industrial, domestic, urbanized, and agricultural waste. The persistence toxicity of heavy metals and their bio-availability have established them as potential pollutants.

Major heavy metals such as mercury (**Hg**), lead (**Pb**), chromium (**Cr),** and cadmium (**Cd**) by virtue of their toxic effects even at minimum concentrations in the bio-available form can enter the food chain and produce a range of serious disorders in the metabolic and physiological systems. However, metals (**Fe** and **Zn**) which are required even at small amount for the natural development of living organisms can become detrimental after reaching to a concentration exceeding their permissible levels. Metals after entering into the aquatic ecosystems bind with particulate matters and then settle down to become a part of the sediments. The contamination of aquatic and soil environments with such toxic materials impose serious threats to aquatic ecosystems, agriculture and human health.

The heavy metals such as chromium(**Cr**), copper(**Cu**), cadmium (**Cd),** and mercury (**Hg**) after being discharged into the water, enter the food chain, and are subsequently bioaccumulated by fish and ultimately pose a threat to human beings. Heavy metals are injurious to health even some of these are known to produce toxicity by inhabiting enzyme action or interfering with blood synthesis of causing damage to the liver, kidney or even to the brain under alkaline **pH** condition, iron gets hydrolyzed and forms insoluble hydroxide, which settles down onto the sediments of the river. The hydroxides and oxides of iron and manganese constitute significant sinks of heavy metals in the aquatic system. These hydroxides and oxides readily absorb or co-precipitate "**cations**" and "**anions**." Even lower concentrations of $\mathbf{Fe(OH)_3}$ and $\mathbf{MnO_2}$ exhibit regulating roles in limiting the distribution of heavy metals in an aquatic system. Besides, the concentration of heavy metals in the sediments depends on **pH**, $\mathbf{CaCO_2}$, and organic matter.

Adsorption of cations by organic matter is due particularly to a negative charge of colloids. The higher concentration of heavy metals in the sediments is often attributed by the precipitation of these metals with carbonates. The metals like chromium (**Cr**), manganese (**Mn**), molybdenum (**Mo**), and nickel (**Ni)** have also shown positive association with organic carbons of the sediments.

5.18.3 Sorption and Desorption: Toxic Contamination of Sediment

Both of the two eco-toxicological processes, **viz**., sorption and desorption, influence the concentration of contaminants especially from the sediment. The dissolved toxic substances are directly linked to environmental damage.

Sorption mainly representing the interaction of a contaminant with a solid is divided into two other processes, i.e., adsorption and absorption. Desorption is the process by which substances are released from the particles back into water. Adsorption refers to the process to enable substances to adhere to the surface of particles, while absorption is the process by which substances actually penetrate into the structure of the particles. These two processes often have different time scales. Sorption may be either absorption or adsorption, or a combination of the two. Owing to the interactions with particulate matter, the behavior of contaminants is affected by the transport, deposition, and resuspension of sediments. Sorption may cause a contaminant to accumulate in sediment bed or bioconcentrate in fish.

Finer fractions of sediments (clays, silts, and organic detritus) often play most important roles for the transport of toxic substances. These fine particles are characterized by size, shape, density, surface area, and surface physical and chemical properties. In general, the smaller the particle size, the greater the surface area/volume ratio and the greater the sorptive capacity for transporting sorbed contaminants. Sorptive capacity, as found in the clay particles of the sediments, displays higher sorptive capacity while sand particles do not possess any sorptive capacity. Particle surface areas also affect the capacity for contaminants to interact with particles. As small particles have greater surface/volume ratios than large particles, it is the smaller (**silt and clay**) sized particles that tend to be more important in determining contaminant behavior. Smaller particles are also more readily carried by flows and waves than large particles.

The fate and transport of toxic substances are regulated by some ecological and hydrogeological processes which include (**1**) inflow and outflow; (**2**) settling of particulates in the water column; (**3**) sorption and desorption both within the water column and the bottom sediment bed; (**4**) exchange between the water column and the sediment bed via deposition/resuspension, diffusion, and bioturbation; (**5**) losses by burial and volatilization; and (**6**) bioaccumulation and transformation.

5.18.4 Fate and Transport Processes

Contaminants in aquatic systems include nutrients, organic toxicants, heavy metals, and pathogens. It has been an established truth that had there been no degradation reactions occurred in nature, every single contaminant discharged, deposited and accumulated in the past, would have polluted the environment. However, natural purification processes dilute, transport, remove, and degrade contaminants which have necessitated to understand the kinetics of reactants quantitatively. The fate and transport processes of contaminants are controlled by two factors: their reactivity and their hydrodynamic transport. Reactivity includes (**1**) chemical processes, (**2**) biological processes, and (**3**) biouptakes. Hydrodynamic transport includes three mass transport processes: (**1**) advection of water current, (**2**) diffusion and turbulent mixing within the water column, and (**3**) deposition and resuspension on the water-sediment bed interface.

5.18.5 Seasonal Dynamics of Heavy Metals in Subarnarekha River, West Bengal, India: A Case Study (Figs. 5.11 and 5.12)

Industrialization, urbanization, and increased population of India have modified environment beyond limits. The problem of environmental pollution is more severe in developing countries like India, because of limited economy and technological resources than the developed countries. The disposal of industrial wastes poses a serious problem at present due to their diverse composition such as acids, alkalis, metallic ions, phenols, cyanide, pesticides, and many other organic and inorganic substances, which have become a pervasive threat to the natural ecosystems.

Environmental toxicants make undesirable changes in several biological processes at cellular, population, community and ecosystem levels of organizations The problem of toxicants affecting aquatic ecosystems is complex and there is continuing need for monitoring and mitigating the effect. The toxicity of heavy metals is of considerable biological and economic interest.

The Subarnarekha River, a major transboundary river in the eastern India, traverses through different landscape areas (mines, industrial field, agricultural field, forest, etc.) of **3** states, viz., Jharkhand, Odisha, and West Bengal, before ending to Bay of Bengal at West Odisha border, India. The unplanned and unregulated mining and mineral processing for the industries have resulted devastating environmental degradation in the upstream of this river. During monsoon, the open and exposed earthen material flows into the river as runoff water and thereby increase suspended solid and heavy metals load, silting the dams and reservoirs. A recent long-term study has revealed that six heavy metals, viz., **Fe, Cu, Cd, Pb, Zn,** and **Cr** exhibited variability in respect of changing seasonal conditions mostly determined by two parameters rainfall and temperature as in other tropical biogeographic zones and also the discharge patterns (industrial, urbans, etc.) at five selected study sites across the river during two consecutive seasons.

Besides trend of bioaccumulation patterns of heavy metals within a dominant benthic faunal (mollusks) deducted several biotic indices also showed distinct differences among different study sites and metals (Figs. 5.11 and 5.12).

5.19 Pollution of River with Nutrients

Freshwater habitats in many parts of world, especially in the tropical countries, have been polluted because of several reasons such as higher nutrient inputs out of human activities coupled with reduced volume of water and global warming-mediated enhanced water temperatures trigger the growth of undesirable algae (Wrona et al. 2006). Enrichment of water bodies with nutrients trigger the profuse growth of the algae which in turn result drastic changes in the structure of the biotic community and cause reduction in oxygen availability. However, exact prediction of undesirable changes in response to different to different aquatic pollutants in conjunction with global warming-mediated environmental impacts is very difficult. For example, higher enrichment with nutrients alongside an elevation of water temperature trigger an increase of biodiversity initially in a cold, and oligotrophic water body, in contrast to the eutrophic aquatic system which in course of time result loss of biodiversity because of reduced oxygen storage capacity (Heino et al. 2009).

Increasing temperature in water bodies also regulate the availability of nutrients and other essential elements within the water as evident from the arctic regions, where melting of upper layers of permafrost liberate phosphorus, which in turn tend to result cascading effects on the productivity of regional streams and lakes (Hobbie et al. 1999).

5.19.1 Nutrient Enrichment of Water and Eutrophication in Rivers

Eutrophication is a process of over-enrichment of nutrients in a water body, resulting in accelerated biological productivity (growth of algae and weeds). Although, eutrophication (from the Greek – meaning "**well nourished**") is a natural process, but human activities have accelerated this process by increasing nutrient loadings by means of various human activities. The time scales for developing natural eutrophication is assumed to be thousands of years, whereas the culture eutrophication due to human activities is the result that takes only a few decades (or even years). Environmental manifestations of eutrophication include algal blooms, reduced water clarity, and oxygen depletion (Fig. 5.10).

Water quality and eutrophication are sometimes used interchangeably to represent the processes of water body enrichment with nutrients. Hydrodynamic processes control the transport of algae, nutrients, and **DO** in a water body. Nutrients, such as phosphorus, after being accumulated in the sediments undergo sorption and desorption process and thereby affect the phosphorus transport and uptake processes which in turn facilitate nutrient cycles and eutrophication. Algae, nutrients, and **DO** are closely linked to each other. Water quality in a water body responds to the watershed, the regional climate, as well as the geometry and internal characteristics and processes of the system. Meteorological forces, internal processes, inflows, and outflows within the riverine systems act like dynamic and dominant factors in determining the water quality. One fundamental challenge to prevent (or to reduce) eutrophication is to understand this complex chain of events and impacts (Fig. 5.10).

During the process of eutrophication, organic detritus mainly derived from the decomposition of dead remains of aquatic biomass release large amounts of nitrates and phosphates in addition to a heterogeneous nutrient source of rivers from the surface runoff and sewage water. The nutrients are then transported by streams and rivers to adjoining large water bodies and make them prone to eutrophication by accumulating nutrients.

Based on its biological productivity and nutrient conditions, a water body can generally be categorized as oligotrophic, mesotrophic, and eutrophic: (**1**), "**Oligotrophic**" represents a water body with low biological activity and excellent water quality, since the water is low in nutrients and algae and both primary production and biomass are severely limited. (**2**), "**Mesotrophic**" water body is characterized with medium biological activity and good water quality. (**3**), "**Eutrophic**" water body is formed because of the over enrichment of nutrients of previous two forms with excessive biological activity and poor water quality. The water bodies endowed abundant nutrients (eutrophicated) and high rates of primary production frequently result in oxygen depletion in the bottom layer. An aquatic system having low nutrient contents is designated as oligotrophic. The trophic state of a water body is largely controlled by nutrient loadings from point and non-point sources, climatologic conditions (sunlight, air temperature, precipitation, and water inflow rates), and the shape of the water body (depth, volume, and surface area. The excessive nutrients produce more phytoplankton than can be consumed by different herbivores and omnivores (zooplankton) in the water body.

This over production can lead to a variety of problems, (**Flow Chart**) which are mentioned below: (**1**) low **DO**, especially near the bottom of the water body; (**2**) high-suspended solids, often enriched with organic material; (**3**) high nutrient concentrations; (**4**) high algal concentrations; (**5**) low light penetration and low water clarity; (**6**) odors from algae or anaerobic muds; and (**7**) changes in species composition. Dissolved oxygen is consumed in the decomposition of algae. Nutrient enrichment within a water body leads to develop blooms of algae which subsequently result a chain of ecological consequences (lowering of **pH**, dissolved oxygen, etc.) because of the death and decomposition of algal biomass which consumes and thereby removes oxygen from the water. The **DO** concentration is usually lowest in summer, when the water temperature is high and the vertical stratification is large.

High rates of decomposition result distinct decrease of **DO** concentration to that extent that pose difficulty in the survivability of oxygen-dependent organisms which are revealed by the mass mortality of fish. Photosynthesis and respiration of excessive plant growth, as well as the microbial breakdown of dead plant matter, contribute to wide fluctuations in **DO** levels. The dense phytoplankton concentrations and their consequences are often perceived as serious water quality degradation, because the impacts can be tangible, such as fish kills and strong odors. Algal blooms prevent light from reaching submerged vegetation that depends on light for photosynthesis. Dramatic changes in the ecosystem can occur when species that die as a result of eutrophication are replaced by species that can tolerate eutrophic conditions. Nutrients are difficult to control because they cycle throughout an ecosystem. Rather than leaving the water body, nutrients can cycle among the water column, algae, and the bottom sediment. Therefore, gradual inputs of nutrients may cause nutrient accumulation in the water body over time. For example, nutrients are taken up by algae. Algal settling and algal mortality result in the transfer of nutrients to the sediment bed. In the summer, with increased temperature, the nutrients return to the water column when the algae decompose and mineralize in the water bottom. The nutrients released from the sediment bed can support the summer algal bloom. This key cycle should be represented well in water quality models.

Major processes affecting nutrient concentration and cycling include (**1**) algal uptake, (**2**) hydrolysis converting particulate organic nutrients into dissolved organic form, (**3**) mineralization and decomposition of dissolved organic nutrients, (**4**) chemical transformations of nutrients, (**5**) sediment sorption and desorption, (**6**) settling of particulate matters, (**7**) nutrient fluxes from the sediment bed, and (**8**) external nutrient loadings.

5.19.2 Pollution by Organic Compounds

Essential of life-supporting organic substances such as proteins, fats, carbohydrates, etc. are found to occur in the sewage derived mostly from the domestic and industrial activities. **Proteins** being the nitrogenous organic substances of high molecular weight constitute the main body constituents of the living world and are constituted by a series (at least **25**) of amino acids which are tied to one another by their carboxyl- and amino-groups to form long polypeptide chains. The chemical elements which are found in the amino acids and in the proteins include mostly carbon, hydrogen, oxygen and nitrogen, and to some extent sulfur and phosphorus as well. **Fats,** mainly derived from the animal and vegetable oils, are characterized in having esters of the trihydric alcohol glycerol ($\mathbf{CH_2OH}$. **CHOH**. $\mathbf{CH_2OH}$) with higher fatty acids (oleic, palmitic, and stearic acids). Fats occur both in municipal sewage and also in the waste water coming out from wool scouring wastes, edible oil, and soap manufacturing industries. **Soaps,** being the washing substances are the metallic salts with higher fatty acids, show chemical similarity with water-soluble sodium salts ("hard" soaps) and potassium salts ("**soft**" soaps) which are prepared by the saponification of fats with boiling solutions of caustic soda and caustic potash, respectively. Alongside distinct presence of soaps in the sewage, and sewage sludges, they are also found in laundry wastes and textile wastes. **Waxes as the** esters of higher fatty acids naturally occur as complex mixtures of lanoline and contain aliphatic hydrocarbons. They are found in the industrial wastewaters from the scouring of wool and paper and textile industries. **Carbohydrates,** being the chief organic compounds used as the major food components of the living animal world (herbivores and omnivores), are composed of carbon, hydrogen, and include the simple sugars, such as glucose, ($\mathbf{C_6H_{12}O_6}$), which constitute the building blocks of high molecular weight polysaccharides such as starch, dextrin, glycogen, alginic acid and cellulose. The main sources of carbohydrates in the sewage is from both domestic and industrial (paper, cotton, silk, etc.) commodities that contain mostly the cellulose. The cellulose, which consists of cellobiose units joined together many thousand times by **1:4**–^-linkages, can be hydrolyzed first to cellobiose, and finally to glucose. **Resins** (amber and common rosin) are complex compounds of carbon, hydrogen, and oxygen found as secretions in many plants, which, after undergoing steam distillation, yields a non-volatile "**rosin**" and a volatile oil of turpentine. Resins are profusely used in the paints manufacturing and textile industries.

5.19.2.1 Effects of Pollution by Organic Matter

Most of the various organic compounds are broken down by microorganisms through the decomposition process within or on the basins of the riverine ecosystem using dissolved oxygen for this biochemical reaction. This has resulted to generate relatively harmless, stable and odorless end products. The river thus recovers naturally from the effects of pollution and is said to have undergone "self-purification." However, continuous dumping of such organic matters lead to exhaust the dissolved oxygen which are used by the microbes for this decomposition process. In absence of sufficient oxygen, decomposition of the remaining organic matter is then undertaken by the anaerobic

bacteria which instead of using free oxygen utilizes combined oxygen in the form of nitrates, sulfates, phosphates, organic compounds, etc. The end products out of such anaerobic decomposition process result different set of end products, (organic amines, organic sulfur compounds, sulphuretted hydrogen, phosphine, etc.) which have objectionable odors and drive away the sensitive species causing an alteration of species composition the riverine ecosystem.

5.20 Synthetic Detergents as Potention Water Pollutants

These chemicals used as cleaning and washing agents include different synthetically derived surfactants (around **30%)** as a part of its formation from a petrochemical, builders (around **15%)** to enhance the functioning of surfactant and other miscellaneous chemical components. Modern pace of development of human civilization coupled with urbanization and industrialization have enhanced many fold usage of synthetic detergents, These a complex inorganic chemical compounds that have been identified as an important sources of aquatic pollution due to their to their ability to cause foam on rivers and at sewage plants even in small amounts. On getting dissolved, the surfactants reduce the surface tension of water developing stable emulsion or suspension with the impurities' that remain in the water (mostly the soil particles) which are required to be removed. The builders (sodium tripolyphosphate, $\mathbf{Na_5P_3O_{10}}$) as a part of the detergent form complexes with the cations, $\mathbf{Ca^{++}}$ or $\mathbf{Mg^{++}}$ and react with the solvent water to build up alkaline solution which accelerates the function of the surfactants.

The very presence of the detergents significantly decrease the rate of re-aeration of river water, adversely affect the efficiency of sewage purification plants, considerably deteriorate the aesthetic of water by inviting bitter tastes and acting as toxic substances to aquatic flora and fauna.

5.21 Hydrocarbon and Oil Pollution in Aquatic Environment: Fossil Fuel Combustion Leading to Formation of Polycyclic Aromatic Hydrocarbons

5.21.1 Hydrocarbon as an Important Toxicants in the River Ecosystem

Carbon dioxide (**CO_2**) and water (**H_2O**) are the major products from combustion of fossil fuels. Besides, combustion of oil and coal produce various hydrocarbons that contain several fused benzenoid rings which are designated as polycyclic aromatic hydrocarbons (**PAHs)**. They are formed by the action of the heat generated during the combustion process and in the condition of oxygen deficiency.

They are considered as pyrolysis products, as pyrolytic **PAHs,** and they have become widespread in the sediments after the industrial revolution and demonstrate the extent of human influence on the environment. Highly peri-condensed **PAHs** are more reactive than **PAHs** exhibiting lower degrees of angular fusion. Their high concentrations among pyrolysis products are supposed to be due to rapid quenching by adsorption (through hydrogen bonding) on some other polycondensed **PAH** material.

Although, all the **PAHs** are virtually insoluble in water, slight differences in solubility exist that would be expected to lead preferential leaching of some components, but this does appear to occur. Further some **PAHs** are susceptible to photo-oxidation than others and might be expected to be preferentially degraded during aerial transport.

The immobilization of **PAHS** within sedimentary matrix is important because many of these compounds are proven carcinogens and it would not be desirable to them to be readily released and subsequently incorporated into the aquatic food chains. Benzo[a]pyrene is a potential carcinogen and its concentration in the sediments of Severn Estuary (**UK**) has been estimated at **ppm** (Thomson and Eglinton 1978).

5.21.2 Oil Spills: Their Ecological Impact on River Ecosystem

Oil is a naturally produced material and therefore ecosystem can cope with certain level of oils, exceeding that amount will cause a series of environmental hazards such as external fouling through emulsification, suppression of primary production by phytoplankton by inhibiting the penetration of solar rays, the reduction of oxygen transfer from the atmosphere, affect the survivability of benthic organisms on sinking to the bottom of water, etc.

Emulsification can also occur soon after an oil spill, as wind and wave action breaks up the oil into fine droplets and disperses within the different strata water column, making the recovery of oil extremely difficult. Alongside, long-term effects on ecosystems are resulted on releasing more toxic components over a prolonged period due to breaking up larger molecules producing derivatives of smaller atomic weights and magnification of concentrations through food chains to the higher trophic levels.

It is really very difficult to tackle the problems associated with oil pollution. Spraying with detergent-based dispersing agents drives the oil deeper into the substrate on sandy and muddy bottoms of water oils have been seen to undergone degradation naturally by the combined actions of weathering, photo-oxidation and bacteria (Coates et al. 1997).

5.22 Eco-physiological Adjustment of Aquatic Biota

A wide range of context dependent variables such as the types, nature, intensity of occurrences, and the history of different disturbances and govern the impacts on populations and communities alongside different human-mediated stressors and abrupt changes of abiotic variables (Johnson and Sumpter 2015).

Besides, the strength of adaptability of the community to overcome such stresses is derived mostly from the prevailing energy stores of the community which in turn depends on the locational advantages of river sites within the frameworks of river network as advocated by the river continuum concept (Vannote et al. 1980). This is evident by the contribution of riparian vegetation to the overall energy budgets of a river through provisioning of organic matter.

Besides, the local populations and communities after being linked up with metapopulation and metacommunity dynamics, in order to achieve recolonization pools relying not only on the framework of river network connectivity but also with overland distances to other network branches (Kärnä et al. 2015). These aspects providing the resilience ability of river ecosystems against the chemical perturbations aim at predicting impacts based on chemical exposure on species interactions inside communities.

This is exemplified by the following notation: if a chemical causes harm to a species **(A)** that interacts with another species **(B)**, the harmful effect of chemical tend to be transferred onto species **B**, which is not directly affected by the toxicant. This phenomenon in the field of ecology is called an indirect effect, though the distinction between trait-mediated and density-mediated indirect effects are hardly established in eco-toxicological studies because of lack of data from field observations or due to the strong laboratory orientation of this subject (Schäfer et al. 2016).

5.23 Mitigation of Pollution

Different mitigation measures to combat the harmful effects several chemical stressors (different pollutants and toxicants) of different categories in riverine ecosystems have been devised and proposed from time to time depending on the scientific and technological innovation and development which range from substitution and reduction of chemicals to effluent treatment and landscape design.

Mitigation measures to decrease the exposure and impacts of all those harmful substances on river ecosystems with the use of compounds for the reduction and substitution having a lower environmental risk. These efforts should take into account of different measures targeting point sources and non-point sources separately. Dealing with case of point sources, the most acceptable mode of used technique is the treatment of the effluent before it is allowed to enter into the water body, for example, in municipal **wastewater treatment plants** (**WWTPs**).

However, such treatments are unable to do justice due to the presence of several persistent chemicals including metals and organic micro-pollutants. In order to overcome such problem, advanced treatment technologies such as chemical precipitation, biosorption, membrane filtration, electrodialysis, etc. have been standardized and implemented to ensure the dilution of concentrations of metals and other organic micropollutants (Schwarzenbach et al. 2006).

However, all those pollution-controlling techniques are having higher waste removal efficiency to generate toxic derivatives from the wastes and also incur high operational costs (Barakat 2012). Activated carbon filtration and ozonation techniques are used to reduce the concentrations of organic micropollutants on an average by approximately **80%,** but the efficiency depends on the chemical properties of the individual chemical (Margot et al. 2013).

5.24 Pollution in Indian Rivers

India, being the largest democratic country of the world, ranks sixth and second in respect of her total area and population. This country is still endowed with several problems such as poverty, illiteracy, poor health index, lack of proper sanitation, unemployment, unplanned growth of cities and towns, disrespect in using eco-friendly technologies, indiscriminate usage of chemical pesticides and fertilizers, construction of many dams and reservoirs on the flowing riverine tracts dislodging the local peoples and destabilizing the habitats of flora and fauna, massive deforestation giving rise not only several wastelands but also increasing the sediment loads to the flowing rivers, etc.

All those developments and factors have contributed in a combined manner leading to severe pollution to most the riverine networks. Such pollution of Indian rivers is highly aggravated particularly in the dry season, when flows are insignificant compared to the monsoon months. Floods during the monsoon flush industrial and municipal pollution into the Ganges and into many other rivers that flow out to the ocean.

The Ganges being the one of the most polluted rivers in the world (Naser et al. 2004) will become even more polluted if the ongoing environmental problems of India go on. Besides the proposed **Interlinking of Rivers** (**ILR**) scheme is supposed to accelerate the intensity of pollution because of the reduction of flows by the diversions of flows as planned under this scheme as evident in the Yamuna river (Gopal and Chauhan, 2006). The environmental flows of Yamuna River and its tributaries have been considerably reduced because of the large-scale withdrawal of water by the state of Haryana and the city of Delhi. Owing to such reduced riverine flows, the water quality of this river, especially in and around the city of Delhi has been deteriorating during last few decades.

Under the interlinking scheme, water from the Ken River, a tributary of the Yamuna is proposed to be diverted to the Betwa River which is expected to reduce the supply of water to the Yamuna River and thereby facilitating the building up of higher concentration of water pollutants and greater intensity of pollution in future. Under the **ILR** scheme, water from the Ganges will also be transferred to the South through the Ganga–Damodar–Subarnarekha and Subarnarekha–Mahanadi links. As the Ganga is already polluted, the interlinking of a polluted river with a relatively non-polluted one will have adverse impacts on the ecosystems of the latter and the people dependent on its waters.

5.24.1 Cleaning River Ganges: Rhetoric and Reality

Water resources are central to life-support systems but are severely threatened by pollution. In India alone nearly **70%** of the available water is polluted and water-borne diseases such as cholera and typhoid account for **80%** of all health problems. As a result, the country loses **73** million man days every year, costing the exchequer more than **250** million pounds sterling annually The Worldwatch Institute in Washington **DC** estimates that **42%** of the Indian population has access to a safe water supply while only **20%** of the population have access to sanitation facilities.

In early **1985**, the Indian government launched the Ganga Action Plan (**GAP**), the major objective of which is to systematically control and monitor the pollution of this significant river. The **GAP** is based on an extensive survey prepared by the Central Board for the Prevention and Control of Water Pollution, New Delhi. The Ganga draining **26%** of the country's land area and carries a quarter of its water resources, enjoys a total catchment area of **900,000 km^2** covering eight states, which accounts for almost **43%** of the irrigated area of India. Besides, not only in terms of physical and economic significance. The River Ganges is with immense religious and symbolic value to the millions of Hindus who bathe in it and use the water for ritual and drinking purposes. People also choose it as the receptacle of their ashes, partially cremated, or unburnt bodies. However, over the years, population growth, urbanization, agricultural practices, and industrialization, coupled with the lack of efficient or adequate sewage treatment and waste disposal systems have all contributed to the contamination of the Ganga making its untreated waters extremely dangerous for direct use.

In its first 5-year phase (1985–1990), **100** million **GAP** will concentrate on the **27** Class **1** cities (population **100,000** or more) situated along the river. The aim is to install or renovate sewage-pumping stations and treatment plants, provide low-cost sanitation facilities, and establish sewerage networks where necessary. Experts maintain that preventing urban sewage from flowing directly into the Ganga would cut pollution levels by **75%**. While work has begun on some of these schemes, the majority have been delayed due to bureaucratic red tape and the constant switching of tenders from foreign companies to local ones. It is doubtful whether the ambitious **1990** project deadline will in fact be met. The extent of foreign aid and the appropriateness of imported technology are being questioned, but very little information is available from the government.

Industries are responsible for treating their own wastewater under the Water Pollution Control Acts of **1974** and **1977**, and the **GAP** is, therefore, not specifically concerned with regulating industrial activities. However, enforcing the Acts can be a problem, partly due to the lack of political will, the lengthy and expensive legal procedures involved, and shortage of funds at the state level to maintain pollution monitoring and regulatory bodies. It is encouraging that the Supreme Court has now begun to address environmental issues and recently closed several industries along the river Ganges (at the cost of employment and development) and has demanded others to install treatment facilities. However, while it may be possible to prevent pollution through the application of technology or controls it is difficult to alter the attitude and consciousness of the people in regard to their relationship with the Ganga. A far-reaching and sustainable public education program will be necessary to change the present situation. One group is working along these lines in the city of Varanasi (Banaras) in the northeastern state of Uttar Pradesh.

Major source of pollution of the Ganges is from the religious city, named Varanasi, located by the side of the midstream of the river Ganga which being one of the oldest cities of the world, enjoy very fertile and alluvial river basins. It derives its name from two tributaries of the Ganga, the Varuna in the north and the Assi in the south. Since ancient times, Varanasi has been known for the production of betel nuts, cotton, silk, carpets; for its educational institutions, and for its religious significance attracting thousands of pilgrims each year.

Hindus believe that death or cremation in Varanasi brings "**moksha**," or liberation for the soul, therefore, the city has a relatively large population of the old, the dying, and the sick. However, the development of Varanasi's infrastructure has not kept pace with the growing residential and fluctuating population. As a result, major problems have emerged, particularly in relation to water supply, sanitation, and storm water drainage. The water quality of the Ganga has been seriously affected as have the lives of the people who depend upon it. Current sources of sewage pollution outfalls from **8** major drains, and more than **70** small household drains are major polluters. This is due to the fact that the city's seven pumping stations cannot cope with the capacity of sewage generated daily (about **100** million liters which even the treatment plant being built will not be able to cope with).

About **30** million dead human bodies are burnt annually at the city's two cremation ghats, Harischandra and Manikarnika, and the resulting ashes, some **100 tonnes** per month, are deposited the Foundation has had to define another center of focus and reassess its tactics and objectives. Another factor in expansion is the difficulty of sustaining action. Since all the executive members have full-time jobs they are not always able to constructively sustain the momentum and interest that is generated by public activities. The office-cum-information center (the Foundation headquarters) is only open in the late evenings, which means that women and children, crucial to the campaign objectives are unable to visit unless accompanied by a male or older family member.

However, enforcing the Acts can be a problem, partly due to the lack of political will, the lengthy and expensive legal procedures involved, and shortage of funds at the state level to maintain pollution monitoring and regulatory bodies. If the Ganga Action Plan(**GAP**) is to be successful and sustainable, especially in the long term when plan funds run out and maintenance of the systems is at stake, then a constructive dialogue is necessary between the macro- and microlevels to define an alternative approach towards the management of an open-access resource such as the Ganga. Pollution control is just one aspect of water management.

The Ganga will not remain clean unless a holistic view is taken which recognizes the extent of deforestation taking place in the upper catchment area (the Himalayas) for which a similar and simultaneous Green Action Plan needs to be launched. The associated loss due to environmental degradation is unlimited. Indiscriminate felling of trees and uncontrolled grazing initiate a vicious cycle of poverty and hill denudation in the hilly areas of the country. The gains of the green and white revolutions in the plain areas cannot be sustained with barren, eroding hills. Poor soils can breed only poverty, but not prosperity. Once denuded and degraded, the process of returning the hills to green and productive land is a difficult business. The cause of hill denudation lies deeply rooted in the social sphere of poverty-ridden hilly villages which were neglected for too long during the process of economic development. Efforts to reforest the hills without concomitant relief of the hardships of the people residing in the affected areas have in most cases been a failure. The people's participation in the afforestation schemes can only be obtained when their economic interests are linked with the protection of the hills.

Though the center has adequate resources these need to be disseminated more effectively; a full-time information officer is required to meet this need. The local administration has installed a river police force and home guards to patrol the river and the ghats to prevent people from dumping rubbish or unburnt dead bodies and animal carcasses, or defecating along the river banks. However, such a policing system only serves to widen the gap between the bureaucracy and the community, or the intended beneficiaries of the **GAP.** If the **GAP** is to be successful and sustainable, especially in the long term when plan funds run out and maintenance of the systems is at stake, then a constructive dialogue is necessary between the macro and micro levels to define an alternative approach towards the management of an open-access resource such as the Ganga. This means, taking into account the significant role played by groups like Swatcha Ganga. Pollution control is just one aspect of water management. The Ganga will not remain clean unless a holistic view is taken which recognizes the extent of deforestation taking place in the upper catchment area (the Himalayas) for which a similar and simultaneous Green Action Plan needs to be launched (Markandya and Murty 2000).

5.24.1.1 Rehabilitation of Degraded Lands in the Himalayan Foothills: Peoples Participation

India is faced with a number of development problems, but rising population and decreasing forest areas are the two major problems that appear to be defying solution. Demands on the diminishing land areas are increasing at the same time as the threats of land degradation are increasing. In India, the soil, which is fundamental to all plant life and ultimately to human survival, is being degraded in several ways. Of the total land area, **80** mha (million hectares) are threatened by water erosion, **20** mha by wind erosion and desertification, **7** mha by excessive salt, **6** mha by water logging and **4** mha by ravines. In addition, large areas are frequently affected by floods and droughts each year.

Soil erosion, the cancer of land, is universally held responsible for the downfall of many previously flourishing empires. As a result of the destruction of forests and natural vegetation in India **6000 million tonnes** of rich soil are being washed to the sea annually due to soil erosion. This soil contains **5.4 million tonnes** of plant nutrients.

The associated loss due to environmental degradation is unlimited. Indiscriminate felling of trees and uncontrolled grazing initiate a vicious cycle of poverty and hill denudation in the hilly areas of the country. The gains of the green and white revolutions in the plain areas cannot be sustained with barren, eroding hills. Poor soils can breed only poverty, but not prosperity. Once denuded and degraded, the process of returning the hills to green and productive land is a difficult business. The cause of hill denudation lies deeply rooted in the social sphere of poverty-ridden hilly villages which were neglected for too long during the process of economic development. Efforts to reforest the hills without concomitant relief of the hardships of the people residing in the affected areas have in most cases been a failure. The people's participation in the afforestation schemes can only be obtained when their economic interests are linked with the protection of the hills. An Operational Research Project started in the foothills of the Himalayas in Haryana State gave rise to tentative hope for the future (Markandya and Murty 2000).

5.24.2 Potential Public Health Implications of Interlinking of Rivers in India

Aiming at fulfilling a multiple of objectives to provide water for human consumption, hydropower and also to eradicate disease associated with malnutrition and poor sanitation, large-scale water development projects are emerging around the world, especially in the developing country. These include infectious and parasitic diseases such as malaria, guinea worm, schistosomiasis (bilharzia), river blindness, and a variety of diarrheal diseases, as well as numerous psychosocial and other indirect health effects. The proposed **Interlinking of Rivers (ILR)** in India without thorough health impact assessments and not developing exact benefits and costs with particular emphasis on the issue of community displacement, malaria, diarrheal diseases such as cholera, and the emergence of parasitic diseases such as schistosomiasis is appeared to become a costly misadventure.

Different dams and reservoirs with the higher storage capacity after being connected with the **ILR** result reduced flow velocity which in turn cause several ecological consequences in river flows with the accumulation of suspended particles, development of eutrophication, depletion of dissolved oxygen, All these changes bring alteration in the biotic community structure with the higher abundance of tolerant species against deteriorating water quality and also accelerate the propagation of vectors of several waterborne diseases such as benthic mollusks, aquatic insects.

Besides salinization and increased water stagnation due to over-irrigation, erosion followed by sedimentation, modification of natural seasonal flow patterns, etc. because of such **ILR** leads to develop several negative ecological consequences especially to the downstream bio-assemblages damaging the fisheries, forests alongside enhancing the exposure to pesticides impacting human health to a considerable extent.

The international health community has been slow to respond to the syndrome created by water development projects – focusing instead on the eradication of single diseases or finding a piecemeal technological, biomedical fix to repeated problems. In the end, most remedies fail to address root causes. While environmental and social impact assessments are often mandatory in the water resource development policies of many countries, including India, health assessments are often not included, even though health is related to both the environmental and social consequences of water resource development (Radhakrishna 2003; Gurjar 2003).

5.24.3 Sardar Sarovar and Its Impact: A Unique Example of Negative Impact of Dam

These people tend to suffer silently from dam development, as they often do not receive compensation for the negative impacts dams have on their communities, and usually represent the poor and marginalized members of society who see little benefit from the hydropower or irrigation systems that are often the driving force behind these huge dams. In the case of the Sardar Sarovar project, this group included people who were displaced by the irrigation canal portion of the project and were not covered under the resettlement plan for those displaced by the dam reservoir. Impacts on communities downstream of dam reservoirs that are not displaced can be equally severe. Many traditional agricultural societies have developed along floodplains and depend on them for their livelihoods.

Decreased flow and nutrient loads downstream can concentrate pollutants, decrease water quality, decrease agricultural and fisheries productivity, and ultimately affect food security and public health. The third group of people that are affected by dams are the immigrants who relocate to be near the dam site and have procured employment with the project in some way, either in manual activities like construction or in higher level activities associated with planning and implementing the project. With migrant worker populations often come increased prostitution and multiple-partner sex, consequently adding **HIV-AIDS** and other sexually transmitted diseases to the list of diseases brought on by development projects (Cernea 1995).

5.25 Pathogens as Contaminant of Water

Pathogens are considered as important contaminant that can potentially cause adverse effects on the physical, chemical, or biological properties of a water body. Contamination of surface water bodies poses serious risks to both aquatic ecosystems and human health. Contaminants in a water body can be taken up by aquatic organisms in a process called bioaccumulation. The prevalance and spreading of diseases are associated with two environmental processes: Hydrodynamic and Sediment processes, Sorption of metal and organic toxicants to sediments is one of the most important processes affecting their fate and transport.

Rivers and streams usually flows unidirectionally to the downstream carrying both the nutrients and the sediments along with different forms of pollutants. Atmospheric deposition is another source of non-point pollution. High runoff is usually accompanied by high loads of sediments that may contain organic contaminants and heavy metals. Microorganisms constituting an important components in the trophic interactions of the riverine ecosystem function as a beneficial agents by offering themselves as food for the members of higher trophic levels such as zooplankton, benthos, fishes etc., as an accelerator of biochemical decomposition process, and serve as a major contributor for of the biogeochemical cycles.

All those activities are for ensuring the stability in ecosystem functioning the survival of ecosystems is impossible without the decomposers. These microorganisms are responsible for converting organic matter to inorganic nutrients that can be used by other plants and animals. They function as decomposers by breaking down plant and animal remains which releases nutrients from the organic matter into the food web. For example, nitrite is formed by the conversion of ammonia by bacteria and subsequently nitrite is converted to nitrate. All those nutrients are used by the organisms (higher plants and animals, and even human beings) present in the higher trophic levels in the food chains. Microorganisms which inhabit within the digestive tract of human beings help digestion process and are excreted in large numbers as pathogenic (disease-causing) bacteria into a water body which in turn cause varying degrees of diseases in humans.

While some pathogens are naturally occurring in the environment, the source of pathogens is usually feces or other wastes of humans and various other warm-blooded animals. These microorganisms may enter water through a number of routes, including agriculture and urban runoffs, malfunctioning septic tanks or sewage plants, or combined storm/sanitary sewer overflows that bypass treatment during storms. Pathogens being very small-sized organisms, once released into the environment, are easily transported by water and are often found densely packed on suspended particulate matters. Pathogens can infect humans through skin contact or ingestion of contaminated water or food. Examples of pathogens include (**1**) bacteria responsible for cholera and typhoid fever; (**2**) viruses responsible for hepatitis and respiratory disease; and (**3**) protozoa responsible for giardiasis. Human exposure can occur not only from eating contaminated shellfish but also from swimming, bathing or engaging in water contact sports in contaminated waters. Fish and shellfish concentrate pathogens in their tissues and may cause illness in persons consuming them. Pathogen contamination can also occur in conjunction with other inorganic pollutants.

5.25.1 Types of Pathogens: Bacteria, Viruses, and Protozoa

Pathogens are commonly grouped into three general categories: (**1**) bacteria, (**2**) viruses, and (**3**) protozoa (Table 5.5).

5.25.1.1 Bacteria

Bacteria are single-celled microorganisms and usually vary in size from **0.5** to **10 mm**. Bacteria are capable of synthesizing cellular materials from either inorganic or organic materials. The bacteria which can function in the absence of oxygen experience anaerobic growth, whereas others (aerobic) require high levels of oxygen for growth. Pathogenic bacteria released into the water by the excretion of human and warm-blooded animals are found in surface waters. The bacteria which belong to the coliform group act as the primary indicators of fecal contamination and the monitoring and assessment of water quality.

It is important to note, however, that most types of bacteria are not pathogenic. The most important group of bacteria with respect to water quality is those associated with the transmission of disease.

5.25.1.2 Virus

Viruses are the simplest form of microorganisms. They require a host to live and cannot grow outside another living organism. Once inside the host, the virus reproduces and manifests the associated illness. The host cell produces more viral particles and liberates them to the environment for further attacks. Viruses attack many types of cells, including bacteria, algae, and animal cells.

5.25.1.3 Protozoa

Protozoa are also single-celled microorganisms that reproduce by binary fission and occur primarily in aquatic environments. Pathogenic protozoa exist in water as cysts. Once ingested, the cysts hatch, grow, and multiply, causing the associated illness. Many diseases can be transmitted by pathogens in water systems. It is important, therefore, to observe whether the disease-causing pathogens are present in a water system and at what level. It is then possible to evaluate the risk of the disease being transmitted to the general public.

5.26 Pollution Impact of Mining Wastes

All forms of mining can result in products and conditions that may contribute to groundwater contamination. The patterns of groundwater recharge and movement responsible for the distribution of contaminants are highly variable and inherently dependent upon the mining practice itself and local conditions of geology, drainage, and hydrology. Associated with both surface and underground mining, refuse piles and slurries are probably the major potential sources of groundwater contamination. Where aquifers underlie these sources, water with a low **pH** and an elevated level of total dissolved solids can percolate to groundwater.

5.26.1 Different Mining Activities and River Ecosystem

The river beds along with its floodplains, river basins, and watersheds are the reservoir of profuse quantity of nonliving resources, the harvesting of which results considerable effects leading to several undesirable changes in the river beds.

5.26.2 Coal Mining: Its Impact on River Ecosystem

The mining of coal has a strong environmental impact on the land and water of the coal fields and on the miners. It has caused a terrifying record of death and injury from explosion, fires, and cave-ins. Another hazard lies in the inhalation of coal dust produced in mines causing the prevalent black lung disease, named as pneumoconiosis. Before the law, about **250** workers died each year in coal mining accidents. Between **1992** and **1994**, the average number of coal mining deaths dropped to fewer than **50** a year. Incidences of black lung disease, caused by exposure to respirable dust in coal mines, has been reduced during the past quarter century by an average of **75%**, and the prevalence of the disease among miners has declined by more than two-thirds.

5.26.3 Sand Mining and Budgeting: Destructing Contribution on River Ecosystem

Proper estimation of the sand budget for a river or stream requires site-specific information with regard to topographic, hydrologic, and hydraulic conditions and also on the amount of sands which are lifted or extracted from an eco-region, located either at upstream or downstream. Such sand extraction process should also not disturb the specific site with unwanted erosion or any eco-degradation because of the possibility of alteration of hydraulics, and textural components of sediments, acceleration of erosion, deterioration water quality, loss of biodiversity etc. A detailed understanding of such ecological changes leading to ecological instability of the channel in response to mining of sand-and-gravels is required to minimize the negative effects Selection of proper time and place to undertake such mining along with developing baseline information pertaining to fluvial processes, biodiversity, and geomorphology of the river also enable to minimize the detrimental effects of mining (Table 5.9).

Sand-and-gravel mining not only disrupt sediment cycling but also modify substantially the channel hydraulics which in turn affect aquatic habitat, depending on the magnitude and frequency of the disturbance, mining methods, particle-size characteristics of the sediment,, All those negative impacts of instream mining on environment is not only restricted to the site of excavation but extend beyond the mining sites, causing the damage of many hectares of fertile agricultural fields and riparian forests, wildlife habitats, loss of fisheries and biodiversity, lowering of recreational potential and aesthetic values in and around the river banks and river basins. These ecologically disruptive activities tend to favor some species over others causing drastic reduction of biodiversity and overall biological productivity.

Anthropogenic activities that accelerate stream bank erosion, lower stream bed elevation, decrease sediment supply from the watershed, etc. cause stream bed instabilities that result degradation of stream habitats for many aquatic species.

Widening of channels causes shallowing of the stream bed, producing braided flow or subsurface inter-gravel flow in riffle areas, reducing habitat complexity and riffle-pool structure, and ultimately result in providing hindrance to the movement and migration of fishes.

5.27 Hydro-Geological Assessment of Water Pollution

5.27.1 Surface Water Pollution

The monitoring and assessment of the water quality of water resources have emerged as an important dimension of water pollution research. During the last decade, attention was focused on many new problems and approaches for their prediction. Besides the pollution from point and non-point sources such as agriculture and deforestation, much attention was paid regarding pollution of not only on river flows but also on the interconnection in between surface water with ground water and also with atmosphere. Precipitation of pollutants from the atmosphere make the water bodies acidic which ultimately percolate to ground water and ultimately contaminate the same (precious water resource of ground water). In such context, detailed small-scale hydrological investigations of a different nature are needed to predict pollution pathways.

It is necessary to research the ways in which polluting substances, under certain conditions, are transformed, combined with other substances, temporarily retarded somewhere, and then suddenly released. Non-point pollutant transport and transformation processes are greatly influenced by vegetation, land use, and soil processes, including snowmelt aspects, and these continue in unsaturated and saturated zones of soils, in rivers and lakes, and, finally, in the estuaries in the brackish interface between the river and the sea. Flow patterns on hill slopes and within the soil profile depend on the interactions between the modified rainfall inputs described previously and the drainage basin geology, pedology, and topography. The nature of these interactions determines the division of hill slope outputs into quick flow and base flow streams, and, thus, has important implications for the form of the storm hydrograph and sediment and solute losses from arid and forest catchments. There is a fundamental distinction between infiltration-excess overland flow and the subsoil and subsoil-related processes, which are highly dependent on site-specific soil moisture and moisture-retention characteristics. Surface of the soil in the aquatic bodies is now being considered as an important hydrological division of the earth If rainfall intensities exceed the infiltration capacity of the soil, the unabsorbed water (minus any losses from evaporation of surface water stores), once the surface detention capacity has been exceeded, runs off downslope via the hydrological process known as infiltration-excess overland flow.

In forest areas, however, infiltration rates are usually high owing to the high hydraulic conductivity of the forest litter layer, good soil aggregate structure, and the presence of macropore channels formed by roots and soil fauna activities. Thus, infiltration-excess overland flow is a relatively limited phenomenon, occurring only where litter dynamics produce ephemeral patches of bare ground, where soil becomes exposed through tree fall, and where land sliding exposes the regolith, such as on steep slopes under high rainfalls or seismic triggering. Further, hydrological processes interact with sediment transport effects, as small-scale landslides in saturated stream head hollows in humid temperate environments appear to lead to channel network extensions.

5.27.2 Groundwater Pollution

The movement of contaminants in groundwater is a particularly active area of research. Models have been developed to study saltwater intrusion as well as leachate migration from waste disposal sites. Groundwater pollutants can be categorized as bacteria, viruses, nitrogen, phosphorus, metals, organics, pesticides, and radioactive materials. This section covers information on subsurface transport in a general way.

5.27.3 Surface–Groundwater Interactions: Relevance of Pollution

There are two general considerations: (**1**) the contribution of pollutants from groundwater to streamflow and (**2**) the delivery of pollutants in surface water into groundwater. Groundwater discharges into major streams, providing perennial flow. This is why streams continue to flow even after many weeks with no runoff-producing events. This interconnection also affects surface water or stream water quality. The pollution of surface water is being considered as the riverine water qualities and is also of concern for its use as drinking water, for recreation, and also for other potential ecological effects.

Over the past years, a great deal of energy has gone into resolving some of our surface water quality problems by developing sewage treatment facilities and by working with industry to control point source discharges into streams and lakes. Yet even where waste treatment effects have been minimized, high nitrate loads have continued or increased in many streams. The occurrence of potentially toxic or hazardous chemicals in ground water, even in low concentrations, is of real concern because of the potential for long-term and widespread exposure to the public. At the present time, only relatively shallow aquifers are affected. However, this may simply be a function of time. Over time, if such chemicals persist in ground water, they may be transmitted to deeper aquifers (Hallberg 1989).

The pesticide concentrations should always remain far below acute toxic (poisonous) levels because of many uncertainties associated with the potential long-term chronic health effects (cancer, immune system disorders) from the ingestion of pesticides in drinking water. These concerns are amplified by the presence of multiple pesticide residues and likely their metabolites, in relation to other environmental factors. Undoubtedly, this is a very important mechanism in the potential rapid leaching of agricultural chemicals (and all land applied chemicals).

5.28 Pollution of River by Hindu Idol Immersion: Practice and Pollution

Water is of special importance in the religion of Hinduism as innumerable devotees possess a long-lasting belief that a holy bath in the waters of the sacred rivers can absolve from all sins and fear of death.

River Ganga being the holiest of all rivers in India is considered to have the power to purify the bather of the sins. Most of the places in India like Haridwar, Varanasi, Patna, Nasik, Talakaveri, and Ujjain are situated along the banks of the seven holy rivers. Idol immersion being an important religious practice of Hindu culture has threatened the riverine ecosystem profusely during last one century. The end of festive ceremony marks the farewell of the deities by immersing them into water with a belief that only Mother Earth can withstand the power and energy hidden within the deities. This practice is seen in the worship of almost all Hindu deities like Durga, Ganesha, Saraswati, and others. Presently, idols are mostly made by non-clay materials and painted with metals rich colors have come into use in idol preparation.

Immersions of the idols, release so many toxic and even persistent components from the immersed idols to the river water causing serious health concern for humans, local aquatic ecology and the total environment. Consequently, the water bodies after the immersions of idols experience lot of changes in the water quality parameters such as an alarming rise of **chemical oxygen demand (C.O.D.)** and **biological oxygen demand (B.O.D.)**, enrichment with nutrients leading to eutrophication, higher accumulation and concentration of oil and grease, increased of turbidity, lowering of **pH** coupled with more availability of heavy metals etc. All such changes have significantly contributed to result significant deterioration of human health on consumption and utilization of this water for drinking and other household purposes. The outcome of idol immersion to the riverine system throughout the length and breadth of the country, India, have revealed an alarming increase of inorganic constituents in the river water such as nitrates, phosphates and toxic metals (**Pb, Cr, Hg, Zn,** etc.), along with the increased level of microbial population. Excess intake of lead to several health hazards such as anemia, colitis, cerebral palsy, hypertension, dysmenorrhea, etc. Besides, through the process of bioaccumulation and bio-magnification of heavy metals, life of several species of fish, reptiles, birds, and mammals are threatened. The floating organic substances released through idol in the river after decomposition result in eutrophication, decrease in the **pH** and **D.O**. increase in the **B.O.D** and heavy metal concentration.

5.29 Wastes and Pollutants Generated from Religious Activities

A huge amount of wastes such as flowers, fruits, polyethylene bags, plaster of Paris, etc. used in the day to day religious activities also are released to the river water causing a lot of toxic effects on the water ecosystem These substances also cause the stagnation of water and develop a favorable condition for the breeding of mosquitoes and other harmful pests.

Several eco-friendly strategies have been adopted to and suggested to tackle the deteriorating ecological conditions of the water bodies which are mentioned below:

1. The same idol should be used every year and immersion of one betel nut may be practiced as a symbol of the ritual.
2. Idols should be made with naturally occurring materials like clay or sandalwood paste which will be dissolved completely in water.
3. Decorating the idols with organically derived garlands, paints derived from the plant extracts, and turmeric-based materials should be followed.
4. Immersing the idols in artificially created small and closed water tanks than large open water bodies should be encouraged.

5.30 Alternative Solutions of the Problems of Idols Immersion

Idols should be made using eco-friendly clay painted with water-soluble and non-toxic natural colors.

1. Keeping aside the traditional practice of making new idols every year, permanent idols should be made with stones or synthetic polymers to be reused each year after performing a symbolic immersion.
2. Avoid public water bodies to immerse the idols, instead immersion of idols may be made in some collected water in an artificial cemented tanks endowed with flow through system instead of immersing idols in public water bodies.
3. Prior to immersion, worship materials like flowers, clothes, ornamental materials made up of metals, plastics, etc. should be removed.
4. Biodegradable materials after collecting separately should be used recycling or composting.
5. Public awareness should be built up on the negative ecological consequences of idols immersion in the natural or pristine water bodies.
6. The "**Idol Immersion Points**" should be in restricted area in order not to allow many peoples to assemble.

5.31 Regulation and Facilitation of Environmental Flows

With increasing regulation of the world's rivers, aquatic ecologists and hydrologists have been focused on understanding the impacts and changes associated with current regulation practices or trying to predict the impact of future regulation practices (Bunn and Arthington 2002; Poff and Zimmerman 2010). With an increasing number of dams and weirs aging in many parts of the world, also it is now challenged with predicting the outcome of removing regulation structures (Bednarek 2001). The approach should be useful for predicting potential future changes associated with flow regulation, transfer of materials to other ecosystems or biotic assemblages but also changes associated with returning rivers to their free-flowing state.

From a broader planning and management perspective, visually explaining patterns of change in model outputs (via ordination) may help identify communities or ecosystems in need of further research or those most susceptible to unacceptable change as a result of human impact and provide additional decision support regarding management investment and effort.

5.32 Pollution Abatements and Conservation Efforts

Most of the existing conservation efforts are piecemeal and instead of becoming proactive remain reactive, at least in part, mainly because of the lack of awareness or interest in mitigation of anthropogenic impacts on rivers.

The ability to ameliorate or mitigate the effects of human activities is predicated upon an adequate understanding of river ecology. Detecting the onset of environmental degradation is problematic and may result in measures to reverse the situation being put in place only after population declines are generally not discernible early enough to permit appropriate remedial action. In the case of Asian river fishes, for example, the lack of data on the extent of inter-annual variation in community composition, although like fish production, may reflect the extent of floodplain inundation in large rivers. The use of zoobenthos abundance data to assess anthropogenic impacts is unlikely to be feasible if natural variation is high.

References

Abdallah, M.D. 1968. The effect of sublethal dosages of DDT, parathion and dieldrin on oviposition of Colorado potato beetle, *Leptinotarsa decemlineata* Say. *Bulletine of Entomological Society of Egypt, Economic Services.* 2: 211–217.

Archer, D., and S. Rahmsterf. 2010. *The climate crisis- An introductory guide to climate change*, 1–248. New York: Cambridge University Press.

Barakat, A., M.E. Baghhdadi, J. Rais, and S. Nadem. 2012. Assessment of heavy metal in surface sediments of Day River at Beni-Mellal region, Morocco. *Research Journal of Environmental and Earth Sciences* 4 (8): 797–806.

Bari, Abdul, V. Ferraro, L.R. Wilson, D. Luttinger, and Liaquat Hussain. 2003. Measurements of gaseous HONO. HNO3, SO2. HCL. NH3. particulate sulfate and PM 2.5 in New York, NY. *Atmospheric Environment* 37 (20): 2825–2835.

Barles, S. 2007. Feeding the city: Food consumption and flow of nitrogen, Paris, 1801–1914. *Science Total Environment* 375: 48–58.

Barnett, A., and B.E. Beisner. 2007. Zooplankton biodiversity and lake trophic state: Explanations invoking resource abundance and distribution. *Ecology* 88: 1675–1686.

Barnett, A.J., K. Finlay, and B.E. Beisner. 2007. Functional diversity of crustacean. *Zooplankton* 52: 796–813.

Barnett, T.P., D.W. Pierce, H.G. Hidalgo, C. Bonfils, B.D. Santer, T. Das, G. Bala, A. Wood, T. Nozawa, A.A. Mirin, D.R. Cayan, and M.D. Dettinger. 2008. Human-induced changes in the hydrology of the Western United States. *Science* 319: 1078–1083.

Bates, B.C., Z.W. Kundzewicz, S. Wu, and J.P. Palutikof, eds. 2008. *Climate change and water. Technical paper VI of the Intergovernmental Panel on Climate Change*. Geneva, Switzerland: IPCC secretariat.

Bednarek, A.T. 2001. Undammimg rivers: A review of the ecological impacts of dam removal. *Environmental Management* 27: 803–814.

Beketov, M.A., and M. Liess. 2012. Ecotoxicology and macroecology -Time for integration. *Environmental Pollution* 162: 247–254.

Benda, L., L.R. Poff, D. Miller, T. Dunne, G. Reeves, M. Pollock, and G. Pess. 2004a. Network dynamics hypothesis: Spatial and temporal organization of physical heterogeneity in rivers. *Bioscience* 54: 413–427.

Benda, L., N.L. Poff, D. Miller, T. Dunne, G. Reeves, G. Pess, and M. Pollock. 2004b. The network dynamics hypothesis: How channel networks structure riverine habitats. *Bioscience* 54 (5): 413–427.

Bergstrom, F.W. 1982. Episodic behavior in badlands: Its effects on channel morphology and sediment yield. In *Sediment budgets and routing in forested drainage basins*, ed. F.J. Swanson, R.J. Janda, T. Dunne, and D.N. Swanston, 59–66. Portland: U.S. Forest Service.

Billen, G., J. Garnier, C. Deligne, and C. Billen. 1999. Estimates of early-industrial inputs of nutrients to river systems: Implication for coastal eutrophication. *Science Total Environment* 243: 43–52.

Biswas, E.R.I. 1972. Changes in the heterotrophic bacteria of Volta Lake, 1968–1971. *Ghana Journal of Science* 12: 72–85.

Biswas, S. 1975. Phytoplankton in Volta Lake, Ghana, during 1964–1973. *Verhandlungen des Internationalen Verein Limnologie*.

———. 1978. Observations on phytoplankton and primary productivity in Volta Lake, Ghana. *Verhandlungen des Internationalen Verein Limnologie* 20: 1672–1676.

Biswas, A.K., and H.N. El-Habr. 1993. Environment and water resources management: The need for a holistic approach. *Water Resources Development* 9: 117–125.

Bond, W.J., and G.F. Midgley. 2000. A proposed CO_2- controlled mechanism of woody plant invasion in grasslands and savannas. *Global Change Biology* 6: 865–869.

Bond, R.M., A.P. Stubblefield, and R.W. van Kirk. 2015. Sensitivity of summer stream temperatures to climate variability and riparian reforestation strategies. *Journal of Hydrology* 4: 267–279.

Bradford, J.M., and C. Huang. 1994. Interril soil erosion as affected by tillage and residue cover. *Soil Tillage Research* 353-361.

Brett, J., and R. 1956. Some principles in the thermal requirements of fishes. *The Quarterly Review of Biology* 31 (2): 75–87.

Brown, A.W.A. 1978. *Ecology of pesticides*. New York: Wiley.

Brown, R.L., and R.K. Peet. 2003. Diversity and invisibility of southern Appalachian plant communities. *Ecology* 84: 32–39.

Brown, K.M., J.E. Alexander, and J.H. Thorp. 1998. Differences in the ecology and distribution of lotic pulmonate and prosobranch gastropods. *American Malacological Bulletin* 14: 91–101.

Brown, R.T., J.K. Agee, and J.F. Franklin. 2004. Forest restoration and fire: Principles in the context of place. *Conservation Biology* 18: 903–912.

Bunn, S.E., and A.H. Arthington. 2002. Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. *Environmental Management* 30 (4): 492–507.

Caissie, D. 2006. The thermal regime of rivers: A review. *Freshwater Biology* 51: 1389–1406.

Calder, I.R. 1990. *Evaporation in the uplands*. Wiley.

Cernea, M.M. 1995. Development's painful social costs: Introductory studies. In *The development dilemma*, 1–31. The Hague: Institute of Social Studies.

Chakraborty, S.K. 2013. Interactions of environmental variables determining the biodiversity of coastal mangrove ecosystem of West Bengal, India. *The Ecoscan* 3 (Special Issue): 251–265.

Chakraborty, S.K., A.K. Paul, J. Bandyopadhyay, D. Banerjee, H. Pakhira, S. Middya, S. Jana, P. Sahoo, K. Paria, and K. Bera. 2013. Sustainable water management in the drought prone riverine tracts of south West Bengal. *Journal of Ground Water Studies* 1: 11–34.

Chakraborty, S.K., S. Maiti Dutta, P.B. Ghosh, R. Ray and A.K. Paul. 2014. *Impact of global warming on Sundarbans mangrove ecosystem, India: Role of different assessment tools from ecosystem monitoring to molecular markers*. Proceedings of the International conference on Green India: Strategic knowledge for combating climate change: Prospects and challenges, pp. 181–200.

Clements, W.H., D.M. Carlisle, J.M. Lazorchak, and P.C. Johnson. 2000. Heavy metals structure benthic communities in Colorado mountain streams. *Ecological Applications* 10: 626–638.

Coates, J.D., J. Woodward, J. Allen, P. Philp, and D.R. Lovley. 1997. Anaerobic degradation of polycyclic aromatic hydrocarbons and alkanes in petroleum -contaminated marine harbor sediments. *Applied and Environmental Microbiology* 63: 3589–3593.

Cole, M., P. Lindeque, C. Halsband, and T.S. Galloway. 2011. Microplastics as contaminants in the marine environment: A review. *Marine Pollution Bulletin* 62: 2588–2597.

Collins, A.L., and S.G. Anthony. 2008. Predicting and sediment inputs to aquatic ecosystems across England Wales under current environmental conditions. *Applied Geography* 28: 281–294.

Collins, A.L., D.E. Walling, and G.J.L. Leeks. 1997. Fingerprinting the origin of fluvial suspended sediment in larger river basins: Combining assessment of spatial provenance and source type. *Geografiska Annaler* 79 (A): 239–254.

Comte, L., and G. Grenouillet. 2015. Distribution shifts of freshwater fish under a variable climate: Comparing climatic, bioclimatic and biotic velocities. *Diversity and Distributions* 21: 1014–1026.

Croke, J.C., P.B. Hairsine, and P. Fogarty. 1999a. Runoff generation and redistribution in logged eucalyptus forests, south eastern Australia. *Journal of Hydrology* 101: 55–77.

———. 1999b. Sediment production, storage and redistribution on logged hillslopes. *Hydrological Processes* 13: 2705–2720.

Cruz, R.V., H. Harasawa, M. Lal, S. Wu, Y. Anokhin, B. Punsalmaa, Y. Honda, M. Jafari, C. Li, and N.H. Ninh. 2007. Asia. In *Climate change 2007. Impacts adaptation and vulnerability. Contribution of working group II to the fourth assessment report of the intergovernmental panel on climate change*, ed. M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden, and C.E. Hanson, 469–506. Cambridge: Cambridge University Press.

CSE. 2009. *Climate change/politics and facts*, 50. New Delhi: CSE.

Das, T., A.K. Pal, S.K. Chakraborty, S.M. Manush, N. Chatterjee, and S.C. Mukherjee. 2004. Thermal tolerance and oxygen consumption of Indian major carps acclimated to four temperatures. *Journal of Thermal Biology* 29: 157–163.

De Lal, R., D. Yleeschauwer, and R.M. Nganje. 1980. Changes in properties of newly cleared Alfisol as affected by mulching. *Soil Science Society of America Journal* 44: 827–833.

Drury, C.F., J.Y. Yang, R. De Long, X.M. Yang, E.C. Huffman, V. Kirkwood, and K. Reid. 2007. Residual soil nitrogen indicator for agricultural land in Canada. *Canadian Journal of Soil Science* 87: 167–177.

Dudgeon, D., A. Arthington, M. Gessner, Z.-I. Kawabata, D. Knowler, C. Lévêque, R. Naiman, A.-H. Prieur-Richard, D. Soto, M. Stiassny, and C. Sullivan. 2006. Freshwater biodiversity: Importance, threats, status and conservation challenges. *Biological Reviews of the Cambridge Philosophical Society* 81: 163–182.

Dunne, T., and L.B. Leopold. 1978. *Water in environmental planning*. San Francisco: W. H. Freeman and Co.

Edwards, C.A. 1973a. *Persistent pesticides in the environment*. 2nd ed, 1–170. Cleveland: C.R.C. Press.

———. 1973b. *Environmental pollution by pesticides*, 1–542. London/New York: Plenum Press.

Edwards, C.A., and A.R. Thompson. 1973. Pesticides and the soil fauna. *Residue Reviews* 45: 1–79.

EEA (European Environment Agency). 2012. *European waters – Assessment of status and pressures*. EEA report no. 8. Copenhagen: EEA. 97 pp.

Englert, D., and M. Bundschuh. 2013. Effects of municipal waste water on aquatic ecosystem structure and function in the receiving stream. *Science of the Total Environment* 454–455: 401–410.

Feng, X., and G. Qiu. 2008. Mercury pollution in Guizhou, Southwestern China -An overview. *Science of the Total Environment* 400: 227–237.

Filipe, A.F., J.E. Lawrence, and N. Bonada. 2013. Vulnerability of stream biota to climate change in Mediterranean climate regions: A synthesis of ecological responses and conservation challenges. *Hydrobiologia*. https://doi.org/10.1007/s10750-012-1244-4.

Firth, P., and S.G. Fisher. 1992. *Global change and fresh water ecosystems*. New York: Springer.

Floehr, T., B.S. Starke, H. Xiao, and J. Koch. 2015. Yangtza three Gorges Reservoir, China: A holistic assessment of organic pollution, mutagenic effects of sediments and genotoxic impacts on fish. *Journal of Environmental Sciences* 38.

Foucher, D., N. Ogrinc, and H. Hintelmann. 2009. Tracing mercury contamination from the Idrija mining region (Slovenia) to the Gulf of Trieste using Hg isotope ratio measurements. *Environmental Science & Technology* 43: 33.

Fry, F.E.J. 1947. Effects of the environment on animal activity. Publications of the Ontario fisheries research. *The Laboratory* 55: 1–62.

Fynlayson, C., and R. D'Cruz. 2005. Inland water systems. In *Millenium ecosystem assessment*, 551–583. Washington, DC: Island Press.

Garnier, J., and J.M. Mouchel. 2013. *Man and river systems: The functioning of river systems at the basin scale*. Dordrecht: Springer.

Giesy, J.P., Keith R. Solomon, Joel R. Coats, Kenneth R. Dixon, Jeffrey M. Giddings, Eugene, and E. Kenaga. 1999. Chlorpyrifos: Ecological risk assessment in North American aquatic environments. *Reviews of Environmental Contamination and Toxicology* 160: 1–129.

Gopal, B., and M. Chauhan. 2006. Biodiversity and its conservation in the Sundarban Mangrove Ecosystem. *Aquatic Sciences* 68 (3): 338–354.

Gosar, M. 2008. Mercury in river sediments, floodplains and plants growing thereon in drainage area of Idrija mine, Slovenia. *Polish Journal of Environmental Studies* 17 (2): 227–236.

Gurjar, B.R. 2003. Interlinking of rivers: A climate view point. *Current Science* 84: 1381–1382.

Haegele, M.A., and R.K. Tucker. 1974. Effects of 15 common environmental pollutants on eggshell thic kness in mallards and coturnix. *Bulletin of Environmental Contamination and Toxicology* 11: 98–102.

Haggart, D., and C. Barret. 1886. *Report of commissioners relative to the restoration of sea fish to the Connecticut River and its tributaries*. Montpelier: Freeman Steam Printing Establishment.

Haidvogi, G. 2018. Historic milestones of human river uses and ecological impacts. In *Riverine Ecosystem Management*, Aquatic Ecology Series, 19–39.

Hallberg, G.R. 1989. Nitrate in ground water in the United States. In *Nitrogen management and ground water protection*, ed. R.F. Follent, 35–74. Amsterdam: Elsevier Science Publishers.

Hartanto, H., and Chay Asdak. 2003. Factors affecting runoff and soil erosion: Plot-level soil loss monitoring for assessing sustainability of forest management. *Forest Ecology and Management* 180 (1–3): 361–374.

Heino, J. 2013. The importance of metacommunity ecology for environmental assessment research in the freshwater realm. *Biological Reviews of the Cambridge Philosophical Society* 88: 166–178.

Heino, J., R. Virkkala, and H. Toivonen. 2009. Climate change and fresh water biodiversity: Detected patterns, future trends and adaptations in northern regions. *Biological Reviews* 84: 39–54.

Hering, D., O. Moog, L. Sandin, and P.F.M. Verdonschot. 2004. Overview and application of the AQEM assessment system. *Hydrobiologia* 516: 1–20.

Hering, D., A. Borja, J. Carstensen, L. Carvalho, M. Elliott, C.K. Feld, A.-S. Heiskanen, R.K. Johnson, J. Moe, D. Pont, A.L. Solheim, and W. Van de Bund. 2010. The European Water Framework Directive at the age of 10: A critical review of the achievements with recommendations for the future. *The Science of the Total Environment* 408: 4007–4019.

Hobbie, S.E., J.C. Finlay, B.D. Janke, Nidzgorski, and D.B. Millet. 2017. Contrasting nitrogen and phosphorus budgets in urban watersheds and implications for managing urban water pollution. *Proceedings of the National Academy of Sciences* 14 (16): 4177–4182.

Hohensinner, S., H. Habersack, M. Jungwirth, and G. Zauner. 2004. Reconstruction of the characteristics of a natural alluvial river-floodplain system and hydromorphological changes following human modifications: The Danube river (1812–1991). *River Research and Applications* 20: 25–41.

Hohensinner, S., M. Jungwirth, S. Muhar, and H. Habersack. 2005a. Historical analyses: A foundation for developing and evaluating river-type specific restoration programs. *International Journal of River Basin Management* 3 (2): 87–96. ISSN-1571–5124.

Hohensinner, S., G. Haidvogl, M. Jungwirth, et al. 2005b. Historical analysis of habitat turnover and age distributions as a reference for restoration of Austrian Danube floodplains. In *River basin management III*, WIT transactions on ecology and the environment, vol. 83, 489–502. Ashurst: WIT Press.

Hohensinner, S., M. Herrnegger, A.P. Blaschke, C. Habereder, G. Haidvogl, T. Hein, M. Jungwirth, and M. WeiB. 2008. Type -specific reference conditions of fluvial landscapes: A search in the past by 3D-reconstruction. *Catena* 75: 200–215.

Hohensinner, S., M. Jungwirth, S. Muhar, and S. Schmutz. 2011. Spatio-temporal habitat dynamics in a changing Danube River landscape 1812–2006. *River Research and Applications* 27: 939–955.

Houghton, J. 2009. *Global warming – The complete briefing*, 1–42. Cambridge: Cambridge University Press.

Imaizumi, Y., N. Suzuki, F. Shiraishi, D. Nakajima, S. Serizawa, T. Sakurai, et al. 2018. Development and validation of a simulation method, PeCHREM, for evaluating spatio- temporal concentration changes of paddy herbicides in rivers. *Environmental Science Processes Impacts* 20: 120–132.

Inbar, M., M. Tamir, and L. Wittenberg. 1998. Runoff and erosion processes after a forest fire in Mount Carmel, a Mediterranean area. *Geomorphology* 24: 17–33.

International Panel for Climate Change (IPCC). 2000. *Special report on emissions scenerios: A special report of working group III of the fourth assessment report of the Intergovermental Panel on Climate Change*, ed. N. Nakicenovic and R. Swart. Cambridge/New York: Cambridge University Press.

———. 2007. *Climate change (2007): Synthesis report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge: Cambridge University Press.

International Panel for Climate Change IPCC. 2007. *Climate change 2007: Impacts, adaptation and vulnerability, contribution of working group II to the fourth assessment report of the*

Intergovernmental Panel on Climate Change, ed. M.L. Parry, O.F. Canziani, J.P. Pabutikof, P.J. van der Linden, and C.E. Hanson. Cambridge University Press.

IPCC. *Technical paper on climate change and biodiversity*. Geneva: Convention on Biological Diversity.

Irwin, D.E., S. Bensch, et al. 2005. Speciation by distance in a ring species. *Science* 307 (5708): 414–416.

Isaak, D.J., and B.E. Rieman. 2013. Stream isotherm shifts from climate change and implications for distributions of ectothermic organisms. *Global Change Biology* 3: 742–751.

Johnson, A.C., and J.P. Sumpter. 2015. Improving the quality of wastewater treatment for removing organic micropollutants. *Water Science Technology* 57: 251–255.

Jones, C.G., J.H. Lawton, and M. Shachak. 1994. Organisms as ecosystem engineers. *Oikos* 69: 373–386.

Jones, C., J. Lawton, and M. Shachak. 1997. Positive and negative effects of organisms as physical ecosystems engineers. *Ecology* 78: 1946–1957.

Karma, N., K.S. Hari Prasad, S. Giri, and A.S. Lodhi. 2015. Intrusion of fine sediments into river bed and its effect on river environment -a research review. *Journal of Hydraulic Engineering* 21 (2): 142–150.

Kaushal, S.s., G.E. Likens, N.A. Jaworski, and M.l. Pace. 2010. Rising stream and river temperatures in the United States. *Frontiers in Ecology and the Environment* 8 (9).

Kaushal, S.S., W.M. Lewis Jr., and J.H. McCutchan Jr. Land use change and nitrogen enrichment of a Rocky Mountain watershed. *Ecological Applications* 16: 299–312.

Keith, J.A., and I.M. Gruchy. 1972. Residue levels of chemical pollutants in North American bird life. In *Proceedings of the XVth international orthinological congress*, ed. K.H. Voous, 437–454. Leiden: E.J. Brill.

Keller, E.A. 1975. Channelization: A search for a better way. *Geology* 3: 246–248.

Keller, E.A. 1978. Pools, riffles, and channelization. *Environmental Geology* 2 (2): 119–127.

Kidd, K.A., P.J. Blanchfield, K.H. Mills, V.P. Palace, R.E. Evans, J.M. Lazorchak, and R.W. Flick. 2007. Collapse of a fish population after exposure to a synthetic estrogen. *Proceedings of the National Academy of Sciences of the United States of America* 104: 8897–8901.

Kraikovsky, A., and J. Lajus. 2010. The neva as metropolitan river of Russia: environment, economy and culture. In *A history of water, series II, 2, rivers and society: from early civilizations to modern times*, ed. T. Tvedt and R. Coopey, 339–364. London: I.B. Tauris.

Lal, R. 2004. Soil carbon sequestration impacts on global climate change and food security. *Science* 304: 1623–1627.

———. 2005. Soil carbon sequestration in natural and managed tropical forest ecosystems. *Journal of Sustainable Forestry* 21: 1–30.

Lal, R., J.A. Delgado, P.M. Groffman, N. Millar, C. Dell, and A. Rotz. 2011. Management to mitigate and adapt to climate change. *Journal of Soil Water Conservation* 66: 276–285.

———. 2008. Black and burried carbons impacts on soil quality and ecosystem services. *Soil and Tillage Research* 99: 1–3.

Margnuson, J.J., L.B. Crowder, and P.A. Medvick. 1979. Temperature as an ecological resource. *American Zoologists* 19: 331–343.

Margnuson, J.J., and B.T. DeStasio. 1997. Thermal niche of fishes and global warming. In *Global warming: Implications for freshwater and marine fish*, ed. C.M. Wood and D.G. McDonald, 377–408. Cambridge: Cambridge University Press.

McCullough, D.A., J.M. Bartholow, H.I. Jager, R.L. Beschta, E.F. Cheslak, M.L. Deas, J.L. Ebersole, J.S. Foot, S.L. Johnson, K.R. Marine, M.G. Mesa, J.H. Petersen, Y. Souchon, K.F. Tiffan, and W.A. Wurtshaugh. 2009. Research in thermal biology: Burning questions for coldwater stream fishes. *Reviews in Fisheries Science* 17: 90–115.

Magnuson, J.J., K.E. Webster, R.A. Assel, C.J. Bowser, P.J. Dillon, J.G. Eaton, H.E. Evans, E.J. Fee, R.I. Hall, L.R. Mortsch, D.W. Schindler, and F.H. Quinn. 1997. Potential effects of climate changes on aquatic systems: Laurentian Great Lakes and precambrian shield region. *Hydrological Processes Vol II*: 825–871.

Malaj, E., P.C. von der Ohe, M. Grote, and R. Kuhne. 2014. Organic chemical jeopardize the health of fresh water ecosystems on the continental scale. *Proceedings of the National Academy of Sciences* 111 (26): 9549–9554.

Malmer, A. 1996. Hydrological effects and nutrient losses of forest plantation establishment on tropical rainforest land in Sabah, Malaysia. *Journal of Hydrology* 174: 129–148.

Maltby, L. 1992. Detritus processing. In *The rivers handbook*, ed. P. Calow and G.E. Petts, vol. 1, 331–353. Oxford: Blackwell Scientific Publications.

Maltby, L., D.M. Forrow, A.B.A. Boxall, P. Calow, and C.I. Betton. 1995. The effects of motorway runoff on freshwater ecosystems: 1. Field study. *Environmental Toxicology and Chemistry* 14: 1079–1092.

Margot, J., C. Kienle, A. Magnet, M. Weil, L. Rossi, L.F. de Alencastro, C. Abegglen, D. Thonney, N. Chevre, M. Scharer, and D.A. Barry. 2013. Treatment of micropollutants in municipal waste water: Ozone or powered activated carbon ? *Science of the Total Environment* 461–462: 480–498.

Markandya, A., and M.N. Murty. 2000. Cleaning up the Ganges: A cost benefit analysis of the Ganga Action Plan (G.A.P) (Published by the Oxford University Press): 1–300.

Mieck, I. 1981. Die Anfange der Umweltschutzgesetzgebung in Frankreich. *Francia* 9: 332.

Miles, J.R.W., and C. R. Harris. 1978. Insecticide residue in water, sediment, and fish of the drainage system of the Holland Marsh, Ontario, Canada, 1972−75. *Journal of Economic Entomology* 71: 125.

Milly, P.C.D., J. Betancourt, M. Falkenmark, and R.M. Hirsch. 2008. Climate change -stationary is dead: Whither water management. *Science* 319 (5863): 573–574.

Mitra, A., A. Dube Gangopadhyay, A. Schmidt, C.K. Andre, and K. Banerjee. 2009. Observed changes in water mass properties in Indian Sundarbans (Northwestern Bay of Bengal) during 1980–2007. *Current Science* 97 (10): 1445–1452.

Newson, M.D. 1992. River conservation and catchment management: A UK perspective. In *River conservation and management*, ed. P.J. Boon, P. Calow, and G.E. Petts, 385–396. Chichester: Wiley.

Nicolson, N.A. 1987. Infants, mothers and other females. In *Primate societies*, ed. B.B. Smuts, D.L. Cheyney, R.M. Seyfarth, R.W. Wrangham, and T.T. Struhsaker, 330–342. Chicago: Chicago University Press.

Odum, E.P. 1971. *Fundamentals of ecology*. Philadelphia: W. B. Saunders Company.

Omerod, S.J. 2004. The golden age of restoration science. *Aquatic Conservation: Marine and Freshwater Ecosystems* 14: 543–549.

Ormerod, S.J. 2004. A golden age of river restoration? *Aquatic Conservation: Marine and Freshwater Ecosystems* 14: 543–549.

Orr, H.G., G.L. Simpson, S. des Clers, G. Watts, M. Hughes, J. Hannaford, M.J. Dunbar, C.L.R. Laize, R.L. Wilby, R.W. Battarbee, and R. Evans. 2014. Detecting changing river temperatures in England and Wales. *Hydrological Processes* 766: 752–766.

Palmer, M.A., C.A. Reidy Liermann, C. Nilsson, M. Flörke, J. Alcamo, P.S. Lake, and N. Bond. 2008. Climate change and the world's river basins: Anticipating management options. *Frontiers in Ecology and the Environment* 6: 81–89.

Paria, K., and S.K. Chakraborty. 2019. Eco-potential of *Aspergillus penicillioides* (F12): Bioremediation and antibacterial activity. *S N Applied Sciences* 1: 1515. (Springer). https://doi.org/10.1007/s42452-019-1545-6.

Paria, K., S.M. Mandal, and S.K. Chakroborty. 2017. Simultaneous removal of Cd(II) and Pb (II) using a fungal isolate, Aspergillus penicillioides (F12) from Subarnarekha Estuary. *International Journal of Environmental Research* 12 (1): 77–86.

Peakall, D.B. 1975. Physiological effects of chlorinated hydrocarbons on avian species. In *Environmental dynamics of pesticides*, ed. R. Hague and V.H. Freed, 343–360. New York: Plenum Press.

Petts, G.E. 1984. *Impounded rivers*. Chichester: Wiley.

Pimentel, D. 1961. Species diversity and insect population outbreaks. *Annals of the Entomological Society of America* 54: 76–86.

Pimentel, D. 1971. Ecological effects of pesticides on non-target species, Executive office of the President, Office of Science and Technology, Washington, D.C., 1−220.

Pimentel, D., C. Wilson, C. McCullum, et al. 1997a. Economic and environmental benefits of biodiversity. *Bio-Science* 47: 747–757.

Pimentel, D., J. Houser, E. Preiss, O. White, H. Fang, L. Mesnick, Tariche Barsky, J. Schreck, and S. Alpert. 1997b. Water resources: Agriculture, the environment, and society. *Bioscience* 47 (2): 97–106.

Pimentel, D., B. Berger, D. Filiberto, et al. 2004. Water resources: Agricultural and environmental issues. *Bioscience* 54: 909–18. 338.

Poff, N.L., and J.K.H. Zimmerman. 2010. Ecological responses to altered flow regimes: A literature review to inform the science and management of environmental flows. *Freshwater Biology* 55: 194–205.

Poff, N.L., J.D. Allan, M.B. Bain, J.R. Karr, K.L. Prestegaard, B.D. Richter, R.E. Sparks, and J.C. Stromberg. 1997. The natural flow regime: A paradigm for river conservation and restoration. *Bioscience* 47: 769–784.

Pye, M.C., I.P. Vaughan, and S.J. Ormerod. 2012. Episodic acidification affects the breakdown and invertebrate colonisation of oak litter. *Freshwater Biology* 57: 2318–2329.

Radhakrishna, B.P. 2003. Linking of major rivers of India: Bane or Boon? *Current Science* 84: 1390–1391.

Randak, T., V. Zlabek, J. Pulkrabova, J. Kolarova, H. Kroupova, Z. Siroka, J. Velisek, Z. Svobodova, and J. Hajslova. 2009. Effects of pollution on chub in the river Elbe, Czech Republic. *Ecotoxicology and Environmental Safety* 72: 737–746.

Reyjol, Y., B. Hugueny, D. Pont, P.G. Bianco, U. Beier, N. Caiola, F. Casals, I.G. Cowx, A. Economou, M.T. Ferreira, G. Haidvogl, R. Noble, A. de Sostoa, T. Vigneron, and T. Virbickas. 2007. Patterns in species richness and endemism of European freshwater fish. *Global Ecology and Biogeography* 16: 65–75.

Richardson et al. 2007. The bottom fauna of the Middle Illinois River 1913–25: Its distribution, abundance, variation and index value in the study of stream pollution. Bulletin Natural History Survey, Chicago 17 (1928): 387.

Schäfer, R.B., B. Kühn, E. Malaj, A. König, and R. Gergs. 2016. Contribution of organic toxicants to multiple stress in river ecosystems. *Freshwater Biology*. https://doi.org/10.1111/fwb.12811.

Schindler, D.W., and J.P. Smol. 2006. Cumulative effects of climate warming and other human activities on freshwaters of Arctic and Subarctic North America. *Ambio: A Journal of the Human Environment* 35 (4): 160–168.

Schindler, D.E., Donald E. Rogers, Mark D. Scheuerel, and Caryn A. Abrey. 2005. Effects of changing climate on zooplankton and juvenile sockeye salmon growth in Southwestern Alaska. *Ecology* 86 (1): 198–209.

Schwarzenbach, R.P., B.I. Escher, K. Fenner, T.B. Hofstetter, C.A. Johnson, U. von Gunten, and B. Wehrli. 2006. The challenge of micropollutants in aquatic systems. *Science* 313: 1072–1077.

Scott, A.J., A.J.M. Baker, S. Whitting, and N., and Chaney, R.L. 2003. Soil moisture effect on uptake of metals by Thlaspi, Alyssum and Berkheya. *Plant and Soil* 256 (1): 325–332.

Seavey, J.R., W.E. Pine III, P. Frederick, L. Sturmer, and M. Berrigan. 2011. Decadal changes in oyster reefs in the Big Bend of Florida's Gulf Coast. *Ecosphere* 2 (10).; Article 114, 1–14.

Smith, Keith. 1972. River water temperatures -an environmental review. *Scottish Geographical Magazine* 88 (3): 211–220.

Sobieszczanski, J. 1968. The influence of different herbicides upon the growth and development of cellulolytic microorganisms. *Annales de l'Institut Pasteur (Paris)* 115: 613–616.

Tabacchi, E., A. Planty-Tabacchi, M.J. Salinas, and H. Décamps. 1996. Landscape structure and diversity in riparian plant communities: A longitudinal comparative study. *Regulated Rivers: Research and Management* 12: 367–390.

Thakre, S.K., and S.N. Saxena. 1972. Effect of soil application of chlorinated insecticides on amino acid composition of maize (Zea mays). *Plant and Soil* 37: 415–418.

Thompson, S., and G. Eglinton. 1978. Composition and sources of pollutant hydrocarbons in the Severn Estuary. *Marine Pollution Bulletin* 9 (5): 133–136.

Torkar, G., and Ž. Zwitter. 2015. Historical impacts of mercury mining and stocking of non-native fish on ichthyofauna in the Idrijca River basin, Slovenia. *Aquatic Sciences* 77: 381–393.
Townsend, C.R., and A.G. Hildrew. 1994. Species traits in relation to a habitat template for river systems. *Freshwater Biology* 31: 265–275.
Troendle, C.A., and J.O. Reuss. 1997. Effect of clear cutting on snow accumulation and water outflow at Fraser, Colorado. *Hydrology and Earth System Sciences* 1: 325–332.
Vannote, R.L., W.G. Minnshall, K.W. Cummins, J.R. Sedell, and C.E. Cushing. 1980. The river continuum concept. *Canadian Journal of Fisheries and Aquatic Sciences* 37: 130–137.
Verma, S.R., S. Rani, and R.C. Dalela. 1983. Pesticides induced dysfunction in carbohydrate metabolism in three fresh water fishes. *Environmental Research* 32 (1): 127–133.
Vethaak, A.D., J. Lahr, S.M. Schrap, A.C. Belford, G.B.J. Rijs, A. Gerristsen, J. de Boer, A.S. Bulder, G.C.M. Grinwis, R.V. Kuiper, J. Legler, T.A.J. Murk, W. Peijnenburg, H.J.M. Verhaar, and P. de Voogt. 2005. An integrated assessment of estrogenic contamination and biological effects in the aquatic environment of the Netherlands. *Chemosphere* 59: 511–524.
Vörösmarty, C.J., P.B. McIntyre, M.O. Gessner, D. Dudgeon, A. Prusevich, P. Green, S. Glidden, S.E. Bunn, C.A. Sullivan, C.R. Liermann, and P.M. Davies. 2010. Global threats to human water security and river biodiversity. *Nature* 467: 555–561.
Vörösmarty, C.J., M. Meybeck, and C.L. Pastore. 2015. Impair-then-repair: A brief history & global-scale hypothesis regarding human- water interactions in the anthropocene. *Daedalus* 144: 94–109.
Ward, J.V., and J.A. Stanford. 1979a. Symposium summary and conclusions. In *The ecology of regulated streams*, ed. J.V. Ward and J.A. Stanford, 377–385. New York: Plenum Press.
———, eds. 1979b. *The ecology of regulated streams*. New York: Plenum Press.
Ward, C., E.B. Bauer, and B.B. Smuts. 2008. Partner preferences and asymmetries in social play among domestic dog, *Canis lupus familiaris*, littermates. *Animal Behaviour* 76 (4): 1187–1199.
Weatherhead, E.K., and N.J.K. Howden. 2009. The relationship between land use and surface water resources in the UK. *Land Use Policy* 26S: S243–S250.
Webb, F.E., and Nobilis. 1995. Aerial forest spraying in Canada in relation to effects on aquatic life, biological problems in water pollution, R. A. Tajt San. Eng. Cent., Technical Report W 60-3 (1960): 66.
Whitehead, P.G., R.L. Wilby, R.W. Battarbee, M. Kernan, and A.J. Wade. 2009. A review of the potential impacts of climate change on surface water quality. *Hydrological Sciences Journal* 54: 101–123.
Wittmer, I.K., H.P. Bader, R. Scheidegger, H. Singer, A. Luck, I. Hanke, C. Carlsson, and C. Stamm. 2010. Significance of urban and agricultural land use for biocide and pesticide dynamics in surface waters. *Water Research* 44: 2850–2862.
Woodward, G., J.P. Benstead, O.S. Beveridge, J. Blanchard, T. Brey, L.E. Brown, W.F. Cross, N. Friberg, T.C. Ings, U. Jacob, S. Jennings, M.E. Ledger, A.M. Milner, J.M. Montoya, E.J. O'Gorman, J.M. Olesen, O.L. Petchey, D.E. Pichler, D.C. Reuman, M.S.A. Thompson, F.J.F. Van Veen, and G. Yvon-Durocher. 2010. Ecological networks in a changing climate. *Advances in Ecological Research* 42: 71–138.
Wright, J.F., P.D. Armitage, and M.T. Furse. 1993. Prediction of invertebrate communities using stream measurements. *Regulated Rivers: Research and Management* 4: 147–155.
Wright, I.A., B.C. Chessman, P.G. Fairweather, and L.J. Benson. 1995. Measuring the impact of sewage effluent on the macroinvertebrate community of an upland stream: The effect of different levels of taxonomic resolution and quantification. *Australian Journal of Ecology* 20: 142–149.
Xenopoulos, M.A., J.A. Downing, M.D. Kumar, S. Menden-Deuer, and M. Voss. 2017. Headwaters to oceans: Ecological and biogeochemical contrasts across the aquatic continuum. *Limnology and Oceanography* 62: S3–S14.

Chapter 6
Land-Use Changes: Floodplains, Dams, and Reservoirs – Integrated River Basins Management

Abstract Since the initiation stage of human civilization, the riverine ecosystems underwent varied form of alterations for the cause of several human-mediated developments through the direct or indirect pathways for harvesting as maximum as possible benefits for the human beings. Direct pathways include activities such as modification of channels and habitats, removal of riparian and aquatic vegetation, changes to flow regimes, or introduction of non-native species. Indirect pathways follow through a change of in land-use patterns that alter peak flows or sediment supply, generate pollutants, or facilitate chemical fertilizers-dependent agriculture that alter nutrient loading to streams.

Both types of pathways influence biological endpoints via changes in habitat structure, stream flow, water quality, energy sources, or biological interactions. Human beings, being the most innovative, creative, partially successful, and also as destructive living organisms have always attempted to grasp more from the environment by not adhering to basic ecological principles for the sustenance of the ecosystems. This adverse environmental impact is being reflected through the arresting of flowing riverine flows in reservoirs behind dams, interlinking of rivers, transferring of freshwater in rivers and streams from one ecozone to another, massive lifting of groundwater, and releasing and dumping of industrial and domestic wastes. Changes in the landform and land use impose considerable impacts on biodiversity and habitat diversity of streams and rivers in multiple scales because of several reasons which include (a) covariation of anthropogenic and natural gradients in the landscape; (b) the existence of a number of scale-dependent mechanisms; (c) existence of nonlinear responses; and (d) the problems in dissociating the present status biodiversity from the historical influences of historical past.

Land-use changes in and around riverine ecosystem include deforestation paving the ways for agriculture expansion, wetlands reclamation, urbanization, and industrialization. Besides, alterations of riverine ecosystem primarily by constructing barrages, dams, irrigation channels, etc. have profusely harm to the overall river ecosystem in general and river biodiversity in particular.

The present chapter has highlighted different facets of relationships of different land-use patterns with riverine flows including the impact of dams on ecological processes function of river ecosystem. The significance of floodplains in determining

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the riverine biophysical processes has been discussed. The main thrust of all such highlights is to develop a holistic understanding on the advantages and disadvantages of both natural and human-mediated land-use changes, so that an integrated river management strategy may emerge.

Case studies pertaining to decadal changes of land uses in the riverine stretches of south West Bengal, India, have also been included to justify the intimate relationships among different land-use changes with the changing ecological condition of rivers.

Keywords Landscape ecology · Riverscapes · Land-use changes: floodplains · Dams and reservoirs: integrated river basins management · Integrated water resource management · Environmental accounting · Alteration of watershed-scale processes · Dams and ecological impacts · Floods with floodplains

6.1 Landscape Ecology and Its Relevance

The importance of changing patterns of landscapes through which the river flows has long been recognized by the river ecologists (Hynes 1975; Vannote et al. 1980). Landscape ecology mostly places emphasis on habitat heterogeneity, connectivity, and scale, all of which have considerable impacts on running water (Snelder and Biggs 2002). Riverine landscapes have been viewed as **riverscapes** based on complex mosaics of different types of habitats having varied form of environmental gradients, which have been developed through ages by high connectivity and spatial complexity (Fausch et al. 2002; Schlosser 1991). Anthropogenic human activities and interventions on riverine environment have appeared to be the prime principal threat to the ecological integrity of river ecosystems, habitats, water quality, and the biodiversity through a multiple ecological via numerous and complex interactional pathways (Palmer et al. 1997; Strayer et al. 2000; Townsend, 1989, 1996; Townsend et al. 1997).

6.1.1 Hierarchies, Habitats, and Biodiversity

Research scientists have explored the hierarchical organization of river, or river basin from the largest spatial scales of landscape to successively smaller valley segment, channel reach, and individual channel units such as microhabitat (Fausch et al. 2002; Frissell et al. 1986, 1998). Many structural elements of the dynamic ecosystem are always interacting and mutually adjusting with one another (Church 2002). Human activities affect water or sediment supply and thereby stabilize or destabilize shape and geomorphology of the rivers and in such process set off a complex cascade of changes that lead to alter and possibly degrade river or stream habitat.

Natural hydrologic high flows in particular, move and sort out sediments, which by way of facilitating the deposition result in different forms of channel features and channel migration. This kind of development also enables to maintain floodplain complex elements within the floodplain river channels and make the land–water interface both complex. The resultant, successional stages of the riverscape with the ever-changing mosaic of habitat patches in all their complexities are largely governed by the high biodiversity of these systems (Robinson et al. 2002). Patch dynamics (Townsend 1989) and relationship between species-specific needs of habitats and requirements of life histories of organisms are very important in the ever-fluctuating mosaic of river and stream habitats in temporal and spatial scales. Assessment of river health and ecological integrity tends to highlight the status of fluvial ecosystems and their response to human influences, which in most cases disrupt the geomorphic features of the riverscape and its associated biota. Different pronounced ecological parameters for assessing the habitat and water qualities attributes can also be evaluated using different biological variables of individual organism or in community in a separate manner or in a combined metrics (Barbour et al. 1999; Baxter and Glaude 1980; Frissell and Ralph 1998; Frissell et al. 1986; Poff 1997; Jansson et al. 1999; Jansson et al. 2000; Jansson et al. 2007; Beechie and Sibley, 1997; Beechie et al. 1994, 2000, 2001).

6.1.2 The Influence of Land Use on Rivers

The global transition from undisturbed to human-dominated landscapes has impacted ecosystems worldwide and made the quantification of land use a valuable indicator of the state of ecosystems (Meyer Turner 1994).

Impacts of several land-use patterns are as follows:

1. Intensification of agricultural land use results in massive degradation of riparian and stream channel habitat ecosystem by increasing non-point pollutants which causes deterioration of ecological qualities of the affected ecozones. Higher inputs of sediments, nutrients, and pesticides are accompanied by agricultural land use (Cooper 1993; Johnson et al. 1997; Lenat and Crawford, 1994).

   Increased nutrient concentrations within the river bed are reported to result in induction and changes in the species composition by altering autotrophic assemblage composition (Delong and Brusven 1998; Quinn et al. 2000). Agricultural insecticide and herbicide runoff from the agricultural field is likely responsible for some of the association between agricultural land use and stream biota (Cooper 1993; Skinner et al. 1997). Rivers and streams in highly agricultural landscapes tend to have poor habitat quality, reflected in declines in habitat indexes and bank stability (Richards et al. 1996a, b; Roth et al. 1996; Wang et al. 1997). Sediments in runoff from cultivated land and animal husbandry activities (Quinn et al. 2000; Strand and Merritt 1999) are considered to be particularly influential instream impairment (Waters 1995). Changes to stream hydrology owing to increased agricultural land use are variable, depending on crop evapotranspiration rates compared to natural vegetation, changes to soil infiltration capacity, extent of drainage systems, and, mode of irrigation (whether water is extracted from the river or from groundwater).

2. Storm flows commonly increase in magnitude and frequency, especially where runoff is enhanced owing to drainage ditches, subsurface drains, and loss of wetland area. In addition to the impact of flow extremes on erosion and habitat, high flows can eliminate taxa if such events occur during sensitive life stages or with sufficient frequency that only resistant and rapidly dispersing species can tolerate them. Macro-invertebrates that are able to withstand dislodgement or that have short and fast life cycles and good colonizing ability predominated in highly agricultural streams (Richards and Host, 1994; Richards et al. 1996a, b). Alterations to flow regime affect stream displacement of early life stages and disruption of spawning ground (Schlosser 1987; Kareiva and Wennergren 1995; Kareiva et al. 2007; Kiffney and Richardson, 2010; Kiffney et al. 2003; Kiffney et al. 2004).
3. Urban land-use activities substantially change the biological assemblages which occurred in increasing catchment area as urban land (Booth and Jackson 1997; Tong and Chen 2002; Usseglio-Polatera and Beisel 2002; Wang et al. 2001). Urbanization has become a prime cause of the disappearance of anadromous fishes (Limburg and Schmide 1990).

Qualitative and quantitative changes in the connected impervious surface was the best single predictor of fish density, diversity, and biotic integrity across a gradient from predominantly agriculture to hardcore urban area. (Wang et al. 2001). Major changes associated with increased urbanization cause an increase in the amount and variety of pollutants in runoff, develop erratic hydrology due to increased impervious surface area and runoff conveyance, and result higher water temperatures because of the shrinkage of the cover of riparian vegetation and warming of surface runoff.

Indeed, biological response measures have been predicted by impervious area in Several landscape studies on landscape pertaining to of stream urbanization have revealed that impervious area can predict the quantum of biological response (Ourso and Frenzel 2003; Walsh et al. 2001; Wang et al. 2001) suggesting that hydrologic influences primary in some studies, but the broader range of influences represented area may be more important in others.

Along a steep gradient of urbanization, macro-invertebrate taxa richness has been found to declined, and tolerant taxa replaced intolerant taxa (Frenzel 2003). Urban land use, chemical factors, channel condition, and habitat are the established cause of changes in the biota and habitat degradation in response to the reduced urbanization flow ability (Morley and Karr 2002; Roy et al. 2004).

6.2 Land-Use Change, Hydrology, and Erosion

Proper evaluation of changing pattern of land use may be used as an indirect evaluation criteria of severe human impact to streams and rivers. The large-scale medieval shifting of land use from forests to agricultural land in Europe during medieval period triggered more soil erosion coupled with excessive surface runoff

Table 6.1 Effects of land-use and land management on flow of rivers

	Volume of runoff	Timing of runoff
Forests		
Planting	Increases if previous cover cleared	More rapid if cultivation/drainage required
Mature cover	Decrease in climates favoring interception or transpiration; increase where snow trapped in forests	More rapid if cultivation/drainage required
Harvesting	Increases until cover reestablished	Location and extent of harvesting critical
Urban		
Surface	Increase in surface volume and totals where replacing crop/forest cover	More rapid as more precipitation retained on surface
Drain/sewer systems	No influence except on groundwater volumes	Most flood flows made more rapid; extreme floods may be ponded in urban area
Agriculture		
Drainage	May reduce long-term storages and reduce low-flow volume	Effect depends on primary soil permeability
Cropping	Evaporative use by irrigated crops reduces net runoff flow	Little direct effect in humid, temperature climates; elsewhere critical to surface runoff and erosion
Mining		
Surface water	Little affected	Restored open-cast often yields rapid runoff
Groundwater	Stored/pumped; boosts low-flow volumes	Little affected

which in turn reduce evapotranspiration and enhanced the discharges of rivers (Table 6.1).

Such observation had resulted in the hypothesis that land-use and land-cover change clearly exhibited positive correlation with erosion rates and thereby establishing a direct link between land-use change, soil erosion rates, and alluvial sediments. Which is hard to prove with the help of conventional method as dating is hardly applicable due to the working and reworking of sediment layers in rivers (Dotterweich 2008; Dreibrodt et al. 2010).

However, the results from few case studies have recorded the links among increased alluvial sedimentation, land-use change, and extreme precipitation events (Dotterweich 2008; Lang 1986; Lang et al. 2003). Human impacts in conjunction with the changes of long-term historical climate and subsequent hydrology of past climate were found to act as the prime drivers of increased sediment storage rates (Giosan et al. 2012).

Besides, alterations of geomorphological features and subsequent habitat changes within the river imposed considerable negative impact on riverine fish assemblages as it was revealed from the study by Pont et al. (2007) for the Drome River, a tributary of the French river, the Rhone.

6.3 Human Need for Integrated Water Resource Management

Human activities are closely linked up with land and water and have necessitated human interventions to derive socioeconomic benefits from the usage of resource bases of rivers and associated ecosystems but also to face the negative ecological consequences generated out of such interventions.

The water divide constitutes a natural physical boundary for examining the interdependence between land and water. This gives the river basin a special relevance from the perspective of integrated land and water conservation and management. River basin being an originally hydrological concept, the development of it should be understood as the development and management of water resources in order to better adapt water availability and meet up the needs of the water for the river biota as well as human beings in time and space.

6.3.1 Integrated and Holistic Environmental Management

Integrated approach in the management of river ecosystem deals the environmental problems in a holistic manner considering the ecosystem as an entity of the entire spectrum of structure and functional ecological processes and also include all possible combinations of proposed solutions.

It is important not to consider solutions to a single problem not keeping aside all other associated problematic issues and also to evaluate all the possible solutions on a long-term basis utilizing the knowledge of all relevant disciplines. Currently, integrated ecological and environmental management consists of a procedure involving seven steps for dealing and solving the environmental issues (Jørgensen and Nielsen 2012):

1. To identify and define the problem
2. To determine the characteristics of the ecosystems
3. To undertake both qualitative and quantitative assessment of the problem
4. To undertake in depth research for developing baseline research information so that the relationship between the problems and the sources of problems could be settled
5. To standardize and utilize all the tools (biological, technological, physical, chemical, etc.) needed to solve the problem
6. To ensure proper implementation of the strategies for achieving solutions
7. To undertake follow-up action for the recovery process. When an environmental problem has been detected, it is necessary to determine and quantify the problem pointing their sources.

A holistic and integrated approach is required in most cases because the problems leading to the corresponding ecological changes in the ecosystems are most often very complex as all environmental problems interact among themselves. The development of several, mostly six (**6**) new ecological sub-disciplines, **viz.**, ecological modeling, ecological indicators, ecological services, ecological engineering, cleaner production, and environmental legislation, to solve the abovementioned problems have become more easier.

6.3.2 An Ecological and Environmental Diagnosis

Ecological models were already developed in the **1920**s by Streeter-Phelps and Lotka-Volterra (2011), but since the **1970**s, many more models dealing with different dimensions ecosystems and emphasizing on the potentiality, threats, and other pollution-mediated problems on ecosystems were developed.

Ecological models being a powerful management tools require in most cases good data, which are resource- and time-consuming to generate expected results. Ecological indicators are categorized based on the spectrum from a more detailed or reductionistic or holistic views to a system or holistic view (Jørgensen 2002). The reductionistic indicators are mostly the chemical compounds causing pollution or a specific species that by their presence or absence can be translated to ecosystem quality. A holistic indicator on the other hand is based on thermodynamic variable or the biodiversity, as determined for the focal ecosystem.

The indicators associated with specific ecosystem health problems can be developed by identifying and devising suitable use of those models. In addition, indicators can become beneficial in environmental management on getting them associated with very clear and specific health problems of the ecosystems.

Over the past **15–20** years, the services offered by ecosystems to society have been discussed, and calculating the economic value of these services has been attempted (Costanza et al. 1997). Assessment of the values of the ecosystem services are also tied with to sustainability, because it is crucial to maintain the many ecosystem services on which society is dependent.

Environmental eco-management strategies for riverine ecosystem preferably derived from the inputs of ecological models have been tested by means of the ecological sustainability trigon (**EST**) (Marques et al. 2009). The use of work energy (**eco-exergy**) as an indicator has been used to assess and also to find out the beneficial value of the ecosystem services, because the development of ecological sustainability is connected with maintenance of the total work capacity (Jørgensen, 2012a, 2012b; Jørgensen and Faith, 2011).

For lakes, rivers, and coastal ecosystems, the use of the quantum of the ecosystem services is much more than for forests and agricultural ecosystems, where the production outcome is directly related by the harvest.

6.3.3 Methods for Solving the Environmental Problems

In order to resolve the environmental problems, several diagnostic tools under several new ecological sub-disciplines have been developed which are discussed below:

1. **Environmental technology**: Environmental technology was available when the emergence of the first green waves started about **45–50** years ago. Environmental management today is more complicated than it was **50** years ago because of the more emphasis on finding out the optimal solution towards emerging global and regional environmental problems.
2. **Ecological engineering (ecotechnology)**: Ecological engineering is meant for designing and achieving of sustainable ecosystems that integrate human society with its natural environment for the mutual benefits of both (Mitsch and Jørgensen 2004).

   Being an engineering discipline, it operates in ecosystems, following well-planned design, scientific principles, and ecological relationships. This new dimension of research methodologies are now being used to find out solutions of environmental problems (for instance, the use of wetlands to treat wastewater). Methods have been developed imitating the natural ecosystems (construction of sewage treatment process following the functional pathways of wetlands to treat wastewater) and also for eco-restoration of ecosystems (for instance, restoration of lakes by biomanipulation with the help of introducing phytoremediators).

   Ecological planning of the landscape is nowadays based on this new development of technique (for instance, the use of agroforestry) The introduction of ecological engineering has made it possible to solve many problems that environmental technology could not solve, first of all non-point pollution problems, followed by a fast restoration of deteriorated ecosystems.
3. **Cleaner production**: Cleaner production means the idea of producing the same commodity or product using new innovative method based on ecological principles (eco-friendly) in order to reduce the emission and thereby cleaning the environment and curtailing the cost of controlling the pollution by adopting several low cost-effective measures such as reuse and recycling of waste materials.

This approach has enabled to develop industrial ecology which involves four basic components based on ecological principles in the industrial production processes:

1. Is based mostly on the use of ecological principles in production such as recycling.
2. Reuse.
3. Holistic solutions in to achieving a high efficiency in the general use of resources.
4. Proper application of environmental legislation.

Adequate freshwater resources and their sustainable utilization have appeared to be vital in ensuring global economic development, environmental protection, and perhaps security. Because of several reasons:

1. Water represents most precious resource base which is necessary for both urban development and food production.
2. It is still remain as an important but underappreciated resource base for component of biodiversity maintenance.
3. It has become very difficult for proper utilization and management of most of the water resource systems to ensure economic development and biodiversity protection simultaneously because of ongoing pollution and human being-mediated stresses such as nonjudicious utilization of resources by multiple, and often inconsistent, demands on it for meeting every increasing human need by way of constructing of dams and reservoirs.
4. These conflicts have become more acute because of the sharing of water of transboundary rivers disobeying international laws international rivers and to fulfill more of the national self-interest, instead of inclining to international cooperation.
5. Limited scope is there to resolve these conflicts in the purview of the roles of international water laws in resolving these conflicts.
6. International water law has been evolved in order to provide a possible framework which can accommodate both river basin development and environmental management, in order to resolve many of the water resource-related problems which may play a more active role in the future.
7. The existing framework works in conjunction with old management paradigm in order to promote the optimum development of river systems giving more emphasis on societal needs.
8. The existing ongoing management systems by altering the natural flow patterns of a river through the construction of dams, diversion systems, and flood control projects accelerate and facilitate the destruction of the ecological integrity of these riverine systems along with their floodplains.
9. This view lays at the heart of the scientific conservation movement which tends to provide the scientific and political bases for the principle of maximum water development. The conceptual base of scientific conservation theory centers around the already persisted theories of production efficiency, which promotes intensive development and maximum economic potential through the implementation of large-scale, multiple-use projects.
10. The process of environmental accounting has recently led to a more radical ecological ideal of the function of river systems and their floodplains. As a result, two alternative visions of the river systems now compete for dominance within the water community. The traditional multiple-use vision of a river system as a commodity to be used to the maximum extent possible is still the dominant vision worldwide. The newer ecological integrity vision is less clearly articulated because it rests on a more complex view of nature and humanity's role in the functioning of natural systems.

This vision is not a simple river preservation concept but rather starts from the premise that human use of a river system should be integrated with the maintenance of its natural environmental sustainability. Water law has taken its cue from the multiple-use vision and has developed doctrines to support that paradigm. Thus, despite recent efforts to reform international water law in light of the global environmental movement, the protection of the ecological integrity of large river systems remains subordinate to the maximum exploitation of these systems.

The multiple-use view fits well with the notion that individuals have the right to modify nature. This deeply imbedded belief impedes the incorporation of a newer vision of ecological sustainability into the law and into the allocation institutions built on the legal principles developed to promote maximum human development and use. Current law, however, must be adapted to modern environmental realities.

The social and economic costs of undisciplined multiple-use development are too high, and international water law should reflect the appreciated value of river systems.

6.4 Differences in the Mode of Uses of Water: Tropics vs Temperate

There are differences also in the uses by man of the rivers of the tropics and the temperate zone. The most prominent of these is that the tropical rivers by and large are not yet used to absorb industrial wastes, though in places they too are being loaded with additions of organic materials, with which they can apparently cope because of their naturally high regenerative capacity and productivity. On the Volga, the Mekong, the Parana, and the Brahmaputra dams can give power, provide water for irrigation, improve the transportation of goods, provide means to control or curb the incursion of salt water in the delta, and create large water body in which fish production may be managed.

Dysfunctions, however, can arise from dams and man-made lakes on large tropical rivers. Proper care should be taken at the time of dam building in the future against the unexpected side effects associated with some of the dams in several parts of the world. A number of adverse effects have been seen since the middle of previous century in building up the dams which are as follows:

1. Changes in the sedimentation patterns
2. Encroachment of fertile lands
3. Removal of aquatic plants
4. Losses in fish stocks
5. Spread of waterborne diseases
6. Destruction of floodplain agriculture
7. Damage to power-generating structures through climate-induced ecological changes.
8. The problems associated with the relocation of people displaced by the waters that accumulate behind the new dams.

6.4.1 Resettlement and Socio-Political Consequences

Some of these resettlement problems as discussed below are threatened to be intractable indeed.

The closure of a dam and the resulting benefits of a closed reservoir, that is, electricity, perennial water, fishing opportunities, etc., become available only after displacement of people. Thus social and political boomerangs are added to the ecological ones already mentioned when one attempts large-scale modifications of rivers.

This does not imply that dams should not be built or rivers regulated but rather more informed and foresighted. In the developed world, the political and administrative instruments of river management face considerable difficulty and mistakes to settle different problems and issues.

In order to resolve the issue, several regulatory bodies have been constituted in developed countries such as river basin commissions, regional planning boards, effluent standards, pollution fines (insufficient though they may be), water resources commissions, and the like. Tropical rivers usually do not have those safeguards.

6.5 Common Alterations to Watershed: Processes and Functions

Human has altered the river ecosystem in various ways. Alongside, human influences on riverine ecosystems common alterations that lead to riverine ecosystem degradation are frequently addressed through watershed or river restoration actions.

6.5.1 Alteration of Watershed-Scale Processes

Most alterations to watershed-scale processes (runoff, erosion, or nutrient delivery) fall into the category of indirect influences on riverine ecosystems because they are changed by land uses that are either far from the stream or widely distributed in a watershed.

Runoff processes are altered through four common effects:

1. Vegetation change or removal
2. Interception of subsurface flow and routing to streams (usually in road ditches)
3. Soil compaction and decreased infiltration
4. Creation of impervious surfaces (pavement, rooftops)

Vegetation removal is particularly relevant in forested areas as removal of trees by logging or land conversion reduces interception and evapotranspiration, which in turn increase annual water yields and flood magnitudes (Harr 1986; Beschta et al. 2000).

This rapid runoff increases flood flow responses to storm events, particularly in small watersheds. Soil compaction by grazing and impervious surfaces in developed areas both decrease infiltration into soils and create more rapid runoff to streams (Trimble and Mendel 1995; Booth and Jackson 1997).

Alterations to runoff processes that reduce stream flow are less common but include afforestation (usually in areas that were previously deforested), creating terraces or berms to capture water on slopes and reduce runoff and decreasing stream flows by dams and withdrawals (Richter et al. 1996; Donato 1998; Spinazola 1998). Changes to sediment supply are caused by a variety of land uses including changes in mass wasting due to logging and road building (Sidle et al. 1985), or increased surface erosion after vegetation clearing, tilling and soil exposure in agricultural fields (Megahan et al. 1995; Trimble and Mendel 1995), increased surface erosion from unpaved road surfaces, and surface erosion and gulling after grazing (Trimble and Mendel 1995).

Mass-wasting processes can be increased by three main mechanisms:

1. Over-steepening of slopes by construction practices (forests, roads, urban, or residential development)
2. Forest clearing and loss of root strength and soil cohesion
3. Concentration of water through road ditches or impervious surfaces and subsequent increases in pore-water pressure in soils on steep slopes

Each of these mechanisms influences the three main hill slope attributes that influence landslide occurrence: steepness of the slope; soil cohesion; and amount of water in the soil. While each of these influences occurs at individual sites, measurable increases in sediment supply at the watershed-scale result from the cumulative increase in number or size of slides in a watershed. Surface erosion is increased primarily by clearing of vegetation or grazing practices.

Many land uses contribute to vegetation clearing, including tilling of fields for agriculture, construction of unpaved roads for logging, and clearing of construction sites for urban or residential development (Megahan et al. 1995; Trimble and Mendel 1995). As with mass wasting, each land use affects a small area within a watershed, but the cumulative effect of multiple actions at multiple sites results in increased fine sediment loading within a watershed.

For example, a small area of logging roads within a watershed may not have a detectable effect on sediment supply at the watershed-scale, but construction of many roads creates a large enough increase in sediment supply to have detectable effects on riverine habitats and biota (Reid et al. 1981). Similarly, tilling of large areas of agricultural land creates substantial increases in sediment supply, whereas small land clearings may only have localized effects if they are near a stream. Nutrients (nitrogen and phosphorous) can effectively become pollutants at high concentrations.

Agricultural runoff, waste-processing plants, urbanization, industrial waste, and other sources can result in elevated concentrations of nutrients, which in turn often lead to nuisance blooms of algae or rooted, aquatic plants (Hudon and Carignan 2008). Supply of nutrients to streams can also be altered by forest harvesting, which reduces the uptake of nutrients in the short term and leads to higher fluxes to streams via groundwater and surface water (Likens et al. 1970; Feller 2005; Nitschke 2005).

In agricultural or urban lands, nutrients from fertilizers are transported to streams, especially during the non-growing season (Lowrance et al. 1985). Nutrients can be delivered to streams via surface runoff, subsurface flow, groundwater flow, and litter and soil inputs from certain nitrogen-fixing species, but use of vegetated buffer strips can reduce nutrient delivery to streams (Lowrance et al. 1984; Osborne and Kovacic 1993; Volk et al. 2003).

Most pollutants are simply alien to riverine environments, including pesticides, metals, and other materials that are often increased by human activity. Pollutant sources can be either point source (urban wastewater treatment plants) or non-point sources (ditches, street runoff, groundwater). Moreover, pollutants can arrive from within a catchment (Kolpin et al. 2002; Kidd et al. 2007), travel long distances as airborne chemicals such as pesticides, mercury, and particulates from combustion (Temme et al. 2007), or by a combination of transport mechanisms. By contrast, point-source discharges of treated sewage or storm runoff can include a vast array of personal care and pharmaceutical compounds, from antibiotics and pesticides to livestock growth hormones, prescription drugs, and even human birth control chemicals (Kolpin et al. 2002; Kidd et al. 2007).

Mining impacts can greatly increase the rates of acidification of water through oxidation of sulfur-dense rock and elevate concentrations of heavy metals with many known health effects (Clements et al. 2010). Many individual pollutants are also bio-magnified up the food chain to higher-level predators, leading to high concentrations of pollutants in some stream fishes.

6.5.2 Sequential Changes River Ecosystem: Alteration of Reach-Scale Processes

Routing and storage of sediment and water through reaches are closely related and are often affected by the same human actions.

The most common and severe alteration is construction of dams, which interrupts downstream water, sediment, and organic matter transport and alters the timing and magnitude of delivery of these resources to downstream reaches. In most cases, dams trap all but the finest of sediments (usually only clay-sized particles remain in suspension through a reservoir), and, if sediment-transporting flows are not significantly reduced by the dam, downstream bed materials coarsen as mobile gravels are transported away, and the channel may incise (Kondolf 1997).

Decreases in sediment-transporting flows can also result in reduced channel size, and the floodplain may become heavily vegetated (Shafroth et al. 2002; Negishi et al. 2008). Reduction of low flows or intermediate flows alters seasonal habitat conditions, establishment or maintenance of riparian vegetation, habitat availability for aquatic biota, and survival of biota that migrate through heavily modified river systems (Kareiva et al. 2000; Poff et al. 2007; Richter and Thomas 2007).

Stream flows are also altered by small-scale diversions for irrigation or other consumptive uses and have many of the same effects on habitats, riparian vegetation, and instream biota as large dams. For example, water abstraction directly impacts aquatic systems by reducing the amount of available habitat through reduced stream flow or degraded water quality, or indirectly by reducing the ability of a system to transport or route sediment.

Finally, gravel extraction directly alters habitat conditions in river and reduces downstream gravel transport, thereby affecting aquatic biota and ecosystem processes (Kondolf 1997). Bank armoring and levee construction are common channel engineering practices that limit channel migration and formation of floodplain channels, which reduces both the habitat and biological diversity in the main channel, side channels, and riparian ecosystems (Fischenich 2003).

Levees dramatically alter floodplain habitats by eliminating flood flows, bank erosion, and access to habitats for aquatic biota. Effects of these changes include reduced habitat capacity for commercially important species (Beechie et al. 1994, 2001) and reduced diversity of floodplain-dependent species. Bank armoring primarily affects bank erosion and formation of floodplain habitats.

While bank armoring has relatively little effect on flood flows, it reduces bank erosion, channel migration, and connectivity between the main channel and floodplain habitats. Bank armoring also alters habitat qualitatively and quantitatively in main river channels, which may also have significant effects on mainstream biota (Fischenich 2003).

Removal of riparian forests has a variety of effects on streams, including dramatically altering the amounts and sizes of wood instreams (Bilby and Ward 1991; Dahlström and Nilsson 2004). Decreases in wood loading tend to impose considerable impact on habitat structure, including reduction in number and sizes of pools, decreased sediment retention and increased gravel size, and altered organic matter transport and storage (Bilby 1981; Montgomery et al. 1995; Beechie and Sibley 1997; Buffington and Montgomery 1997). Management of animal husbandary by promoting and encouraging open grazing, removal of vegetation, and modern technology based agricultural activities, together impose destabilizing effect on channel width and form, as reductions in root strength can lead to increased bank erosion, channel widening, and conversion of single-thread channels to braided channels (Sweeney et al. 2004; Zanoni et al. 2008).

Removing riparian vegetation, especially to the bank, can also result in higher inflows of nutrients and pollutants to stream reaches (Correll 2005), or in changes to the amount and composition of leaf litter delivered to streams (Kiffney Richardson 2010). Both of these effects can ultimately lead to changes in food web dynamics instreams.

6.6 Impact of Reservoirs on Riverine Flows

Most large rivers have been altered significantly from their natural state. Globally, **172** of **292** large river systems are impacted by dams (Nilsson et al. 2005). For example, **70%** of the discharge from the **139** largest rivers in North America, Europe, and the former Soviet Union is affected by irrigation, diversion, or reservoirs.

Most of the unaffected river systems that remain in these regions are in the far north (Dynesius and Nilsson 1994). Reservoirs cause sediments to settle from rivers, and rivers downstream become "**sediment starved**" and significantly more erosive. Natural sandbars are less likely to form in a starved river (Baxter and Glaude 1980; Frissell and Ralph 1998; Beechie et al. 2000; Stanley 1990; Likens et al. 1981; Nilsson and Wardle 2005).

Reservoirs can also alter the riparian habitat by interfering with flooding; in dry, sandy rivers, they allow establishment of more riparian vegetation and reduce the width of the channel (Friedman et al. 1998). Dams also fragment riparian habitat, leading to distinct changes in plant communities by altering patterns of dispersal and recruitment (Nilsson et al. 1997; Jansson et al. 2000).

6.7 Community Relocation and Resettlement in India

After Independence from Britain in 1947, water resource development became a major focus of the Indian government, which has constructed approximately 4000 dams in the last several decades, and more than half of them were built between 1971 and 1989 (Rangachari et al. 2000) making a huge area submerged and displaced peoples enormously (IRN 2007; Roy 1999). The focus of water development projects in India, especially during **1960**s, was on population relocation rather than rehabilitation and restoration of livelihoods and property.

The people who are affected by the dam-dependent irrigation schemes are forced to relocate because their former homes are to be submerged by reservoirs or irrigation channels. Alongside the compensation packages offered by the government, peoples often see some benefits, such as irrigation canals for agriculture or electricity, from the development project. Yet, the intangible costs are great.

Loss of sense of community is perhaps the largest and most intangible consequence of displacement and takes an untold toll on mental health. Increases in morbidity and mortality, including an increase in malnutrition, have also been documented (Hemadri 2000). These increases in morbidity and mortality can have obvious effects on mental health as well, as stress levels increase among the survivors.

6.8 Impact of Dams: Displacement of People and Related Problems

While displacement has been a major political issue in India, particularly surrounding the Narmada Dam in Gujarat, little attention has been focused on the public health consequences of dams. Irrigation and hydropower may improve the standard of living for some, but the increased incidence of infectious diseases may reduce quality of life for others.

Health benefits and disease outcomes are very difficult to quantify, but a cost can be placed on disease control and treatment, and this can be weighed against the potential benefits of hydropower, improved agricultural yield, and even improvements in health for some because of access to clean water, better nutrition, or increased availability of electricity. It should also be noted that some positive health effects of large water development projects are also possible.

During the construction phase, new infrastructure such as roads and communication systems are often brought in. These roads can provide better access to hospitals and healthcare and improve the flow of information into a community. After the construction project is completed, food security and access to safe drinking water can improve (Figs. 6.18, 6.19, 6.20 and Table 6.2).

6.8.1 Dams vs Biodiversity

Biodiversity within a river is determined by a multitude of eco–bio–geological factors of which intensity of riverine flows play as the most important variable by determining all characteristics of the physical habitat which enable the biotic components to settle, colonize, grow, and propagate. Resisting the flows of by creating some built structure in the form of reservoirs or dams or barrages for the purpose of storage, diversion and abstraction of water to meet the growing and divergent human needs have altered the flows drastically to the extent that many long stretches of even large rivers remain dry for most of the year through a variety of structural interventions. This artificial development also prevent the normal movement of nutrients, sediments, fishes, seeds, or propagules of plants and other aquatic organisms towards downstream and their disturb normal trophic relationship.

Besides, fragmentation of rivers leads to develop metapopulation of biota and promotes inbreeding leading even to extinction of species. The migratory species of fish fail to reach their downstream nursery grounds for seasonal breeding and spawning by losing longitudinal connectivity.

Table 6.2 The top countries worldwide by number of large dams

	Country	ICOLD World Register of Dams 1998	Other sources	Percent of total dams
1	China	1855	22,000	46.2
2	United States	6375	6575	13.8
3	India	4011	4291	9.0
4	Japan	1077	2675	5.6
5	Spain	1187	1196	2.5
6	Canada	793	793	1.7
7	South Korea	765	765	1.6
8	Turkey	625	625	1.3
9	Brazil	594	594	1.2
10	France	569	569	1.2
11	South Africa	539	539	1.1
12	Mexico	537	537	1.1
13	Italy	524	524	1.1
14	United Kingdom	517	517	1.1
15	Australia	486	486	1.0
16	Norway	335	335	0.7
17	Germany	311	311	0.7
18	Albania	306	306	0.6
19	Romania	246	246	0.5
20	Zimbabwe	213	213	0.4
	Others	3558	3558	7.0
	Total	**25,423**	**47,655**	**100.0**

Source: WCD (2000)

6.9 Water Development by Dams and Public Health

6.9.1 Malaria

Malaria is a parasitic infection transmitted by the Anopheles mosquito. Mosquito larvae thrive in stagnant water, and increased incidence of malaria is often associated with irrigation projects and dams in areas of seasonal malaria transmission (Klinkenberg et al. 2003).

Year-round standing water can lengthen the season of transmission and increase the range of the activities of vector by changing micro-climatic conditions and create an endemic area from an area previously affected only by sporadic epidemics (Jobin 1999). An analysis of potential increase in vector-borne disease in **13** out of the **67** dams examined by the World Commission on Dams' India has substantiated the claim that contruction of dams display positive relationship with the vector borne diseases (Rangachari et al. 2000).

Even so, the Ministry of Health is typically not involved in planning water development projects, and remedial measures are usually proposed as solutions, rather than preventative measures to minimize amount of standing water and maximize drainage. Remedial recommendations have included establishment of Primary Health Centers to treat affected individuals or distribution of insecticides to kill the mosquito larvae. These measures have their own associated costs. The use of insecticides, in particular, has potentially negative health consequences (WHO 2006).

6.9.2 Schistosomiasis

Schistosomiasis, also known as bilharzia, is a parasitic illness transmitted by a snail vector that thrives in slow-moving water. The parasite typically infects either the urinary or intestinal tracts, and while one can live for years with no acute effects, the chronic effects are crippling and often fatal. The illness is due to eggs released by the female worm once lodged in the target organ of the body.

The eggs can cause calcification of the bladder, painful urination, blood in the urine, and, ultimately, damage to the urethra, kidneys, bladder, and, in advanced cases, bladder cancer. IEggs after being lodged in the intestinal tissues can result in continuous enlargement of the liver and spleen. This disease has become tragically epidemic around large dams in much of the developing world; it has not, however, been recently detected in India, but with increased water development, researchers have become increasingly concerned about the possibility of establishing the disease.

The low prevalence of schistosomiasis in India as compared with neighboring China can be partially explained by the high intensity of rainfall in India during the monsoon season (Jobin 1999).

6.9.3 Cholera

Because of decreasing water quality and increased fecal coliform levels, cholera is a serious risk in India. Cholera is a serious diarrheal illness caused by the bacteria *Vibrio cholera*. Incidence of cholera has a cyclic relationship with the monsoon season in India. Populations of *Vibrio cholera* have been shown to be regulated by bacterial viruses known as phages. After periods of heavy rain or severe flooding, phage concentrations in aquatic environments tend to be low, allowing the bacteria population to flourish (Faruqi 2003). The cholera bacterium is also associated with various aquatic organisms, especially zooplankton with chitinous skeletons, such as copepods (Lipp 2002). As aquatic ecosystems become more productive due to increased nutrient loads, it can sustain more microorganisms including cholera bacteria.

6.10 Dams and Its Impact on Groundwater

Dams can negatively impact groundwater as well as surface water quality. In the southern Indian state of Andhra Pradesh, "**knock-knee**" (Genu valgum), a crippling bone disease due to increased consumption of fluoride, has been associated with the construction of the Junasagar Dam. Seepage from reservoirs and irrigation channels have contributed substantially for the enhancement of the subsoil water levels, and also increasing of the fluoride concentration in groundwater where fluoride was already present. This syndrome has also been associated with at least two other dams in India: Parambikulam in Columbatore and Hospet dam in Karnataka (WHO 2000). Conversely, some argue that when more surface water is available for human consumption, the pressure on groundwater reserves will decrease, therefore avoiding the consumption of naturally occurring contaminants such as fluoride and arsenic.

This is the argument put forth by proponents of the Sardar Sarovar Dam in Gujarat, where fluorosis is a major health problem in the arid Kutch region (Vyas et al. 2010).

6.11 Dam Building: Ecological Perspectives of Past vs Present

Dams being the most important intervention of human being on riverine ecosystem are one example of the increasing pressure on river services.

Mostly, dams were built for multifarious purposes such as to gain for hydroelectric power, fisheries, water sports, and transport, but they supported also the creation of fishponds or, in dryer areas, irrigation of agricultural land, etc. The modern dams had significantly modified ecological conditions by acting as sediment traps and altering channel morphology.

After the building up of thousands of milldams between the seventeenth and nineteenth centuries by the European settlers, **1–5 m** of slack-water sedimentation had covered the floodplains and the existing meandering river channels incised in these sediments (Walter and Merritts 2008). The number of newly constructed dams increased exponentially across the countries of the world during the late nineteenth to the end of the twentieth century.

A summary on dam construction during the last couple of centuries has revealed an increasing trend first in the north and then in the south which ultimately resulted a consistent increase during the entire the twentieth century (Rosenberg et al. 2000). Spanning a period of one decade (1950s), around **3000** new dam projects were implemented. In the **1990**s, almost 2000 new constructions of dams took place all over the world. In the **2000**s and **2010**s, the number further decreased to some extent, but Zarfl et al. (2015) have predicted that after 2020s, new dam construction will resume (Lehner et al. 2011).

The ecological effects of modern dams include the reduction of velocity which ultimately leads to transform the lotic water bodies to a lentic one almost having no currents of water with different sizes, fluctuating water temperature, etc. influencing the bioenergetics and trophic relationships of aquatic organisms of organisms (Poff and Hart 2002).

Besides, movement of water and sediment towards downstream is influenced and reduced with adverse effect on river and riparian habitats and ultimately leads to alter the biogeochemical cycles in the rivers and riparian habitats. Dams hamper migration of aquatic organisms including fishes and other aquatic organisms and exchange of nutrients in between upstream and downstream.

6.12 Ecosystem Approach to River Basin

The river basin is an ecosystem subject to multiple uses. The river basin provides a natural boundary to evaluate the ecosystems contained therein. In most ecosystems there is no actual membrane separating system from environment. The boundary in most cases remains as imaginary and is visualized as being connecting to the surrounding biosphere by a system of inputs and outputs which are represented in the form of radiant energy, water, gases, chemicals, or organic materials which are moved, transformed, and cycled among the different compartment of the ecosystem by different meteorological, geological, or biological processes.

The ecosystem approaches involve an integrated or transdisciplinary approach to deal with the functioning of food webs which have appeared to become fundamental for the sustenance of rivers as ecosystems alongside maintaining associated aquatic and terrestrial communities of river basins. The current emphasis on restoring rivers as ecosystems habitat structure are in need of explicitly adhering to the fundamental ecological principles, driving the proper functioning of the ecosystem, with special emphasis of food web complexity and dynamics in order to enhance survival potential of the targeted species by combating ongoing environmental perturbations and other constraints.

Three identified food web-related issues that potentially impede successful river restoration are as follows:

1. Uncertainty and lack of proper assessment of about habitat carrying capacity
2. Proper identification of increasing concentration of chemicals and contaminants
3. Understanding of new development of hybrid food webs involving both in containing a mixture of native and invasive species.

Additionally, the analysis and interpretation of food web dynamics can be used to derive information of the consequences of altered nutrient cycling, organic matter and energy availability, pattern of water flows and, modes of thermal regimes, reconnecting of critical habitats with their food webs in a broad temporal and spatial frameworks, which can act as prerequisites for the effective ecomanagement and thereby ecorestoration of eco-degraded ecosystem restoring changing environments (Table 6.1).

6.12.1 Floodplain: Contribution Towards River Ecosystem

Floodplains are formed over millions of years by flooding of rivers and deposition of sand on river banks (Fig. 6.19). These sandy floodplains with sandy sediments represent an unique and exceptional aquifers where any withdrawal of water is counterbalanced and compensated by gravity flow from a large surrounding area. A floodplain is a functional part of a fluvial system.

Its form is the product of a large number of interrelated processes that change over time in response to external factors which include allocyclic factors such as climate change, which cause variation in the runoff, biological communities, weathering rate, and sediment flux.

6.12.1.1 Relation of Floods with Floodplains

Floods play an effective role in controlling the morphology, the ecology, and the sediment distribution of a floodplain which is defined as an area of relatively low relief, adjacent to a stream that must experience floods at least once in a given period.

Floodwater is either derived as overflow from the parent channel or result from local runoff or intense rainfall (Nanson and Croke 1992; Alexander et al. 1935). The difficulty in defining a floodplain increases with discharge variability. In areas with erratic discharge (e.g., in areas of unreliable monsoon rainfall, erratic tropical cyclone patterns), the definition of a **100**-year flood (or **200**-year flood) and delineation of inundation area is difficult – due to often short-monitoring periods and the extent of channel and overbank change that occurs with successive large discharge events.

In yet more extreme cases where flow is ephemeral, any hydraulic definition of the floodplain becomes problematic, especially in extreme cases where the parent channel may be defined poorly and may change with each discharge event.

6.12.1.2 The Distinction Between Channel and Floodplain

Most definitions of floodplains refer to the area adjacent to the mainstream, and the channel is not included in the floodplain although tributary and distributary streams may be. In contrast, some regard the floodplain as the whole low-lying area including the channel(s).

The latter obviates the problems associated with distinguishing the channel in ephemeral or erratic discharge systems but is less satisfactory for many purposes, such as planning regulation. If the main channel(s) is regarded as distinct from the floodplain area, it is necessary to define the boundary between floodplain and channel and establish criteria for the point where a channel bar becomes part of the floodplain (Perez-Arlucea and Smith 1999).

6.12.1.3 Floodplain Formation and Functions: Floods and Aquifers

Much of the damage caused by inundation of floodplains occurs by relatively concentrated flows down features resembling infilled remainders of river channels; these so-called palaeochannels also provide the best indication of floodplain formation processes. These processes are strongly interlinked to lateral mobility of active river channels.

As sinuous patterns evolve and migrate, valley sides become eroded; the active channel therefore creates a wider valley in which both flood waters and sediments can be stored. The storage of sediments is a salient property of the transfer system, and in confined river reaches, there is clearly a throughput of both flow and load until spreading can occur.

In regions which have experienced climatic fluctuations, particularly glaciation, valleys tend to have adjusted to the flow of ice or to substantial melt water streams. Sediments enter floodplain storage in two principal ways: by deposition in the channel (as bars and shoals) followed by abandonment, through migration, of that channel, or by out-of-bank flows.

Clearly, the former mechanism favors coarse clasts of sediment and the latter fine clasts; the result is that floodplains are frequently composite, with coarse materials below, topped by fines. A further environment for the deposition of fines is the "**backwater**," partially abandoned, channels of alluvial (silt/clay) reaches. Therefore, considerable modification of flow patterns occurs across the floodplain which is supposed to be accompanied by beneficial chemical changes such as nutrient stripping (Pinay and Decamps 1988).

6.12.1.4 Floodplain Modifications by Man

The generalized form of river valley of the developed world is now a wide corridor of intensive land use and water use. Since settlements and infrastructures cannot continually move in response to flood or drought, floodplains have become regulated with more or less respect for natural dynamics according to culture, cost, and severity of natural impacts.

In a polarized case, the following developments may have occurred:

(**a**) Channel straightened and erosion-proofed
(**b**) Extensive flood protection structures
(**c**) Extensive irrigation and/or drainage
(**d**) Eradication of natural vegetation and destruction of wetlands
(**e**) Encroachment of buildings and structures towards the channel
(**f**) Use of floodplain and channels/palaeochannels for waste disposal

These all result from the exploitative nature of the development processes which have necessitated to undertake more serious approach to fulfill competing objectives of conservation of rivers and floodplains.

6.12.1.5 Floodplains: Interdisciplinary Approaches

1. Floodplains act as an extraordinary reservoir of biodiversity and exhibit higher biological productivity. Being a very productive landscape with a mosaics of different habitats with different ecological features that are intensely inhabited by different forms of flora and fauna and used by human being for a multitude of reasons (industries, fishing, recreation, energy, etc.), this threatened landscape sustaining human intervention has suffered from proper eco-management.
2. Distinct and sharp of ecological characters of natural floodplains in respect of catchment size and character, climatic conditions, discharge characters, and sediment load through different seasons and years at different locations have made the biological communities to become very sensitive to these variations. Besides, plant communities with very different evolutionary histories tend to flourish in the major floodplains of the world.
3. Floodplain character has undergone marked changes through geological time alongside because of the evolution of land plants and animals, in tune with the changing atmospheric chemistry, global climate, and sea level changes. However, recent changes have also occurred because of recent past human activities (forest clearance, multifarious uses of water, construction of different built structures on use, and channel engineering) which have brought about rapid changes in this landscape.
4. Floodplains representing the sinks for the fine-grained materials account for most of the transport loss as sediment moves through the system. This information, together with the sediment profiles, have established the facts of storage and transportation of several pollutants such as heavy metals, pesticides, and fertilizers which after being associated with particular grain sizes of sediment remain stored in the floodplains for long periods.

   Eventually, these may be mobilized to develop serious biological consequences. Some floodplains and particular processes, such as channel bank accretion, have been studied intensively, sometimes with duplication of research effort, while other areas and processes have been largely ignored.
5. For millennia, human beings preferred to be intimately associated with the floodplains as the favored sites for human habitation, because of the availability of water supply, fertile soil, navigable waterways, and flat terrain for building and communication. Long-term management of floodplains for many human purposes has been obscured or destroyed.
6. Floodplain management involves several human-mediated activities such as construction of different various flood defense systems, engineering activities related to navigation, water-powered mills, irrigation, agriculture, drainage, wetland management for wildlife, etc.
7. In addition to all those, indirect management results from engineering works for floodplains, which affect floodwater paths.

6.12.1.6 Floodplain Ecosystems: Ecological Uniqueness

In tune with the emerging industrial cultures, different forms of industrial activities have been increasing at an alarming pace causing the large-scale modification of river–floodplain ecosystems to such an the extent that it poses real difficulty to recognize major variables that once regulated the systems and to account for the survivability of biota which are very much for the once determine the functioning of the ecosystem.

However, human-based modifications, especially for flood control devices, jeopardize the natural fabric of ecosystem functioning, principally because all those modifications act to resist regular flooding. The dynamic interactions among the different living and nonliving parameters of the water and land constitute the principal river–floodplains building process, any disturbance of which ultimately affect the adaptations of biota as revealed from the studies both from the tropical and temperate floodplain systems (Junk et al. 1989).

The flood-pulse concept after being enunciated tends to identify and assess the predictable water budgeting (advancement and retraction of water) within an idealistic natural floodplain representing a pristine system as the controlling measure on the abundance and distribution of most of the floodplain biota. This concept highlights, therefore, the flood pulse as is not a disturbance but instead a significant deviation from the average hydrological regime. It is also postulated that the flood pulse can boost up the biological productivity by enhancing the diversity of plants and other biota, increasing the nutrients, detritus and modifying the texture of sediments in the system.

A gradient of plant species adapted to seasonal degrees of inundation, nutrients, and light exists along the aquatic and terrestrial transit zones, scientifically designated as the floodplain (Junk et al. 1989). Therefore, the floodplain represents that part of the river ecosystem which is regularly flooded and dried, projecting it as a type of wetland.

The ecologically suitable zone for biological activity within the floodplain is the shallow water littoral zone (Junk et al. 1989), near which is present an inshore area zone from where flooding and drawdown within floodplain take place (Junk et al. 1989). Such movement of water in the floodplain results high turnover rates of organic matters and nutrients which are mostly found to occur as a result of this movement.

During flooding, nutrients previously mineralized during the preceding dry summer period get dissolved. Additional nutrients which remain either as dissolved chemical components or as suspended sediment in the flood water are brought in from the main river. Such inputs of nutrients and sediments either in the form of dissolved or suspended forms trigger the rates of primary production and accelerate the decomposition process during flooding.

For example, annual net production by the grass species of the floodplains of the Amazon River, South America, was estimated as 99 tons of dry matter per hectare

(Piedade et al. 1991), which exceeded far above the total primary production recorded in other natural environments (Leith and Whittaker 1975). Litter productions from the herbaceous macrophytes and tree plants have been estimated to make up **69%** and **24%** of the total annual net production, respectively, whereas the remaining **7%** production were represented by the phytoplankton and periphyton in a partially deforested area of the Amazon floodplain (Bayley 1989).

Despite this high production from the vascular plants, the alternating terrestrial and aquatic phases decompose plant matters in the similar manner at which it is produced, but accumulation of detritus has not been observed in regularly flooded areas (Junk and Furch 1991). Halting of rising water level reduces the depth of the water bodies and enhances the decomposition processes in contrast of the increase relative to production, resulting dissolved oxygen deficiency, which in turn leads to the production of hydrogen sulfide from sulfate reduction.

The responses of much of the higher biota, including fish, mammals, and invertebrates, to the flood cycle are expressed as characteristic adaptations across all river–floodplain ecosystems (Junk et al. 1989).The moving littoral during flooding provides excellent nursery grounds for fish and optimal conducive environmental set ups for many invertebrates, especially those which are associated with macrophytes (Junk 1973) and adult fish. Therefore, most fish species anticipate these conditions by swimming before or during the water rise.

During drawdown, production is appeared to be high due to effects of nutrient accumulation. Fish are compelled to grow as fast as possible during flood period so that they can reach to sufficient size which can enable them also to resist predation pressures. In contrast, during dry period the water volume is drastically reduced during dry period which in turn retard the fish growth to its minimum.

River–floodplain biota display high annual growth and mortality rates (r-selected traits) (Pianka 1970). They have evolved life history strategies that enable them to rapidly colonize to large areas and thereby causing higher survivability and abundance of fish. This ability helps species to persist, because of variability in the flood regime from year to year results in different areas of the floodplain being accessible and optimal for growth and survival.

Variability in dissolved oxygen among different ecozones of the riverine tracts has is caused by a number of a number of ecological factors and orocesses such as wind velocity, water currents, effects from thermocline and decomposition processes that occur throughout the hydrological cycle. Water temperatures also play important roles in determining the higher somatic production during the period of drawdown, whereas invertebrates prey are expected to get the benefit from nutrient runoff.

Decomposition rates of flooded herbaceous vegetation are found to be slower at the lower temperatures, resulting to more vegetative cover and favorable substrates for fish and invertebrates to flourish during drawdown.

6.12.1.7 Ecological Benefits of River–Floodplain Ecosystems

The benefits of maintaining genetic and species diversity and preserving unique natural phenomena should be self-evident. Less obvious is the benefit of enhanced production.

The flood pulse concept implies that biological production is enhanced through a variety of processes during the flooding cycle. It has been hypothesized by Bayley 1991 that an optimal rate of increase in the water level at floodplains maximise production. Biological processes at the time of higher production phase in the littoral zones are not able to keep pace with the advance of water level.

Conversely, oxygen deficiency caused by the lower production rate inhibits fauna and decomposition rates. Also, on an annual cycle, fast rates of rise and fall would limit the time that aquatic biota could spend on the floodplain, whereas low rates would limit how much floodplain would be inundated.

Therefore, rates of rise and fall would be expected to influence the annual production of aquatic biota, as well as the timing of temperature regimes. Although special studies are needed to examine specific hypotheses that consider elements of the hydrological cycle, the available data allow testing of the more general hypotheses that a flood pulse advantage would increase biological productivity per unit water area above the level expected from equivalent stable water bodies.

Fish yield from all multispecies fisheries can be regarded as interesting as variety of aquatic and terrestrial production processes in the river–floodplain. The combined area of rivers and permanent lentic water bodies is small compared to the average inundated area of the associated floodplains and many riverine species depend on resources from the floodplains, and many riverine species depend on resources from the floodplain (Junk et al. 1989; Welcomme 1985).

Therefore, the majority of fish species that do not depend directly or indirectly on floodplain production cannot contribute significantly to the yield. Moreover, yields in river–floodplains tend to be underestimated compared to lakes, because of the inadequacy of most estimated methods in accounting for the highly dispersed fishing activities in river systems (Bayley and Petrere 1989).

6.12.1.8 Research Strategies: Floodplain Ecosystem

Research approaches to the understanding and predicting of the ecological structure and function in river-flood plain ecosystems must explicitly account at small spatial (meters or tens of meters) and temporal (hours or days) scales in the floodplain, where a large variety of mechanisms operate to determine the growth and other biological functioning of individuals and populations within floodplains biotic community (Welcomme 1985) and thereby is being projected as the probable cause is of variation in the quantities and compositions of flora and fauna.

It is difficult to attempt microcosm approaches to determine what mechanisms are most likely to determine and regulate biotic processes on the much of the larger scales (in kilometers and hydrological seasons) necessary for understanding principal system functions, estimating limits of resource exploitation and planning conservation and restoration strategies.

In a floodplain, ecological patches (Pickett and White 1985) are determined by hydrology and geomorphology which in turn are determined by depth, flow, and plant association. Therefore, it is assumed that the tropical systems can be applied to temperate systems by understanding how processes may deviate from a general, conceptual model such as the flood pulse concept. In this regard, the effects of temperature interactions with hydrological parameters/regimes on biota are critical.

Both in the tropical and temperate systems, the effect of variance in the hydrological regime, especially due to seasonal impacts put ecophysiological stresses on biota which have evolved the power of resistance against such hydrological variation and recycling by mobilizing and harvesting the accumulated organic matter and nutrients, generated through the process of recycling (Colwell, 1974).

Therefore, any study of energy transfer among trophic levels should explicitly account for seasonal accumulation and breakdown rates of the various forms of particulate and dissolved organic matter. Lag effects of recycling of organic matter or nutrients at cooler temperatures may result in qualitatively different production processes. For example, secondary processes that depend on released nutrients and plant growth may be fast enough to accompany the moving littoral in tropical systems, whereas at cooler temperatures other processes may use the nutrient regeneration later on in permanent lentic or lotic zones after flood has subsided.

Finally, systems under restoration require special consideration. Landscaping of the floodplain is problematic, because it requires accurate prediction of the dynamics of water and sediment transport, of the effects of those dynamics on the colonization of vascular plant and maintenance and vice versa.

6.12.1.9 Need for Ecosystem Management of Large Rivers and Their Floodplains

Ecosystem management takes into consideration different natural driving forces and their variability in river ecosystems with the prime objective of recovering biological integrity and maintaining ecological stability. Out of **79** large river–floodplain ecosystems of the world, majority has undergone considerable alterations because of human activities, and unaltered ones are expected to follow the same path soon (Welcomme 1985).

These complex ecosystems are composed of the flowing channels that most people associate with rivers, together with floodplain lakes, backwaters, forest, and wetlands that harbor much of the earth's terrestrial and freshwater biodiversity. River–floodplain ecosystems unlike most lakes are characterized by seasonal floods which promote the to and fro movements of nutrients and organisms among a mosaic of habitats in order to enhance biological productivity (Bayley 1989, 1991; Junk et al. 1989).

The predictable and long lasting characteristics of a annual flood pulses force the plants, animals and even human societies to develop adaptability in order not only to overcome the adverse ecological condition but also to take advantage of the changed ecological situation. In ancient Egypt and Mesopotamia, the fertility of soils was renewed each year by the annual overflow of the rivers, and thereby sustain large population in one place for millennia permitting and paving the way for the development of great civilizations.

Outside these floodplains, the fertility was exhausted within a few years because of steady cultivation and thereby compelled the people to move on. In such venture, flood pulses are being focused as they drive these systems. The great floods of **1993–1994** in Asia, Europe, and North America raised the public awareness, to a considerable height paving the opportunity to undertake changed river management policies.

6.12.1.10 Importance of Large River–Floodplain Ecosystems

The public is aware of the high biodiversity of tropical rain forests, but few people realize that many of the forests are on floodplains, as in Amazon basin (Welcomme 1979, 1985, 1995). Large river–floodplain ecosystems are often species rich, for a variety of reasons having to do with the age, size, habitat complexity, and variability.

In the tropics, the flood pulse provides a strong seasonal cycle in an environment that is otherwise unseasonal. The flood pulses may have been responsible for the evolution of an annual seasonality in life cycle that eventually enabled tropical insects to colonize temperate zones (Erwin and Adis 1982; Junk et al. 1989).

In geologically old rivers such as the Mississippi and Amazon, species of both flora and fauna have had enough time to diversify and exploit the complex array of available habitats (Goulding 1980; Junk et al. 1989). Even hypoxic backwater swamps are occupied by many groups of fishes with a variety of physiological and anatomical adaptations to low oxygen, including air breathing (the tropical lung fishes, Dipnoi).

Large rivers usually have numerous tributary systems where new aquatic species can form through geographic isolation (Moyle and Herbold 1987). Species richness not only depends on speciation but also on avoidance of extinction, particularly in the temperate zones of the world with their more variable climates and periodic glaciations.

6.13 Refuges and Migration Corridors: Climate Change-Related Influence

In addition to conserving species, during harsh climatic periods over time scales of millennia, river–floodplain ecosystems provide refuges during annual or decadal droughts as well as corridors for spectacular annual migrations.

Most fish undertake much shorter migrations within the river–floodplain ecosystem and its tributaries, but there is one long-distance aquatic migrant that rivals the birds. In both tropical and temperate rivers, fishes undertake both longitudinal (along the river channel) and lateral (across the floodplain) migrations to spawning and feeding areas, because optimal conditions for both activities vary with the flood cycle and do not often occur simultaneously in the same areas (Welcomme 1985; Vörösmarty et al. 2000).

In temperate rivers, many fishes migrate to off-channel wintering areas seeking refuge from low temperatures and currents. Currents require swimming to maintain position at a time when food supplies and metabolism are low.

6.14 Long-Distance Links: Exchange of Materials

Large rivers link distant ecosystems, including deltas and coastal zones, not only through animal migrations but also by the transport of water, sediments, nutrients, and contaminants.

Some migrations counteract the natural tendency of materials to be carried downstream by the flowing water. Large rivers consisting mainly of many interwoven network of channels can have large-scale eddies, bed forms (sand dunes), man-made spur dikes extending out from the banks, mussel beds, and woody debris that retard the downstream flux of organic matter, sediments, and nutrients (Bhowmick and Adams 1990).

Floodplains provide even greater opportunity for retention of nutrients and production and processing of organic matter before delivery to the sea. Particles and the nutrients adsorbed on them settle out in slack-water areas during floods or are ingested by filter feeders. Dissolved nutrients carried in the through the main riverine channel the may be taken up by microorganisms or aquatic macrophytes growing in shallow, floodplains.

Floodplains serve as sources or sinks for organic matter and nutrients which depend on characteristics of the flood and floodplains. Vorosmarty et al. (1986) have estimated that **35%** of the total nitrogen entering the Mississippi and its tributaries from the watershed is retained or lost (through denitrification) within the rivers and impoundments before reaching the sea.

Whether floodplains are sources or sinks for organic matter and nutrients depends on characteristics of the flood and floodplains. Junk et al. (1989) have defined the inshore edge of a flood as it traverses the floodplain as the "moving littoral," and they hypothesize that biological productivity is stimulated by release of nutrients from the newly flooded soil.

In temperate zones, production may also be boosted during spring floods by solar warming of cool channel water on the floodplain. In both tropical and temperate rivers, fish yield per acre is found to be higher to a great extent in rivers with flood pulses and floodplains in comparison to the fish diversity and productivity in nearby impoundments where flood pulses are very feeble or absent.

Bayley (1991) calls this phenomenon derived from an effect of flood pulse as "**Flood pulse advantage**" (Welcomme 1979, 1985). Organic matter produced on the floodplain or carried in by the floods can be rapidly decomposed in the moist floodplain environment until the availability of oxygen becomes limiting.

Flooded soils and bottom layer of water in the floodplain lakes often become anaerobic some time during the flood cycle, so duration of the flood strongly influences nutrient fluxes. Speed of decomposition gears up when the water recedes and the soils and leaf litter become oxygenated within the floodplains again. If the water recedes too rapidly off the floodplains, organic matter, nutrients, and newly hatched aquatic organisms may be carried into river instead of remaining in the floodplain and permanent backwater.

6.14.1 Consequences of Altering Natural Processes and Connectivity

Leveeing floodplains from their rivers to prevent flooding and enhancement of agricultural use of the rich alluvium soils eliminates the flood pulse advantage to the fisheries in the remaintaining aquatic environment. On land, the natural nutrient-replenishment system once provided by the flood must be replaced with commercial fertilizer.

Some societies practice a flood-adapted form of aquaculture, agriculture or harvest both fish and a compatible crop, such as through rice cum fish culture, but intensive, high yield agriculture often invite conflicts with fisheries, particularly due to the indiscriminate application of pesticides that contaminate fish through bio-magnification (Welcomme 1979, 1985). The channelized or leeved rivers lack the vegetated riparian buffers mostly depend on the eco-sustaining ability of the floodplains that could take up nutrients and ameliorate the effect of increased nutrient-loading of rivers and sreams by facilitating the development of steady run-off from heavily fertilised lands.

Downstream sediment transport can be interrupted by sediment trapping behind upstream storage dams, and lateral sediment transport can be interrupted by leeves. Both of these interruptions have serious long-term consequences. The newly deposited sediments are relatively watery and dispersed, but they become more compact during the dry spell when the organic matter they contain get oxidised and with the squeezing out of water from the or overlying sediment.

The resulting subsidence and coastal erosion of in the Mississippi delta threaten both man-made structures and the wetland nurseries of freshwater and estuarine species (Penland and Boyd 1985; Sparks 1992; Stanley 1995; Sparks et al. 1990, 1998).

6.15 Dams: General Perceptions

Development of human civilization is intimately connected with the riverine systems on which dams have imposed great negative impact on modifying the riverine flows along with its ecology and thereby caused lot of constraints to the human society in deriving benefits from the rivers.

Over the course of human development, water control structures have played a central role in the advancement of societies. Communities have been prospered and grew because of the development of sufficient freshwater sources by building canals, channels, or watercourses; reservoirs, where water is collected and stored for future use; earthen dams or other barriers across watercourses to capture water; and dikes, ditches, or levees to deliver water to fields and for drinking water (Table 6.2).

Despite obvious economic and social benefits, some hydrologic structures, particularly dams, due to their ability to impound large quantities of water, have posed considerable environmental damage, both locally and regionally. One immediate impact of a dam is flooding caused by water held up river. Where previous upland has become submerged, millions of residents have had to relocate, and many valuable plant and animal habitats have been eliminated.

Dams also hinder and reduce the flows towards downstream, which impacts the ecology and biota of the watershed. While almost all dams return water to a stream through controlled gates in the structure, the water that is released often is altered.

6.15.1 Benefits from Dams

At present, out of the **45,000** large dams in the world, two-thirds are in the People's Republic of China. Asia, North America, and Europe account for more than **95%** of dams built. Africa is marginal in these statistics with hardly more than a few hundred. Dams have made a major contribution to the progress of human societies, enabling them to control their water resources for human needs:

(**i**) Comes from irrigated farming contributes **40%** of world food production, of which **16%** contributions are derived from land irrigated from dam reservoirs. It has been estimated that **30–40%** of the **268** million hectares of irrigated lands is watered from dams.

(**ii**) Hydroelectric power produces **19%** of the total energy produced in the globe and is used in more than **150** countries.

(**iii**) In North America, **60%** of water requirements in towns and cities are supplied by **12%** of large dams.

(**iv**) In nearly **75** countries, **13%** of the world's dams help control river floods and flooding.

(**v**) Some dams have helped to improve ecosystems by creating new wetlands and new opportunities for fishing and recreation in the reservoirs.

(vi) Considering the abovementioned facts, it can be inferred that dams have become the parts and parcel for ensuring human development and also for providing a multitude of the benefits to the human beings.

6.15.2 Problems with Dams

Some of the problems which are commonly associated with dams are:

(i) Most of the world's large dams have been unable to achieve the technical, economic, and social objectives for which they were designed. Many of them have typically fallen short of physical targets, did not recover their costs, and have been less profitable in economic terms than expected.

(ii) The impacts of large dams on river ecosystem are generally very negative, especially by resulting serious irrecoverable loss of biodiversity and eco-degradation of ecosystems. It is very difficult to combat the harmful effects of new reservoirs on river ecosystems and biodiversity of rivers and adjoining terrestrial habitats with a good number of wild species.

(iii) Large dams have serious consequences on the living conditions and culture of populations, especially indigenous people.

They have displaced large numbers of people, who, when resettled, have been unable to recover acceptable conditions of existence. People affected by the negative impacts have not always enjoyed the benefits from the dam.

(iv) The riparian forest being the habitats of so many sensitive wildlife undergoes eco-degradation especially in the upstream catchment areas due to inundation of the reservoir area.

(v) The different biotic components of river ecosystem, especially the fishes of both upstream and downstream floodplains, wetlands, and riverine, estuarine, and adjacent marine ecosystems, are lost considerably.

(vi) The construction of a number of dams on the same river renders cumulative impacts on water quality, species composition, and flooding.

(vii) Long-term loss of storage mainly because of sedimentation has become a serious concern all over the world, and consequently this will increase the erosion rates, which are felt within the dams having smaller storage volumes mostly located in the lower reaches of rivers.

(viii) Water and salinity and water logging affect a considerable area of land irrigated by large dams globally by imposing, long-term and often permanent impacts on land, agriculture land, and livelihoods of human beings.

(ix) In several occasions unacceptable and often unnecessary costs are being paid to secure the social and environmental benefits, by displaced people and communities, by taxpayers.

(x) Nonequital distribution of benefits has raised the questions on the value of many dams towards meeting water and energy for the needs of development when compared to the alternatives.

(**xi**) The rights of the persons who bear the risks associated with different management options for water and energy resources development should be amicably settled in order to make a positive resolution of competing interests and conflicts.

6.15.3 Socioeconomic Impacts of Dams

(**i**) Poorly managed involuntary displacement and loss of livelihood.

(**ii**) Most of the displaced people do not get proper compensation and also are deprived of getting the scopes of settlement.

(**iii**) Depriving the indigenous people of the means to support traditional ways of life, particularly in case of culturally vulnerable indigenous/ethnic minority groups who have traditional and inherent rights of locally available natural resources.

(**iv**) Higher incidences of waterborne diseases particularly among vulnerable communities.

(**v**) Low regional economic development reforms and inadequate distribution of project benefits to affected communities.

(**vi**) Short time mitigation of most of the impacts because of the construction of reservoirs or dams on both terrestrial and aquatic ecosystems along with their biodiversity has become very difficult, and efforts to "rescue" wildlife have met little long-term success.

(**vii**) Overcoming the blockage of migratory fish has had little success, because most of the existing technologies do not address the problems associated with the specific sites and species.

(**viii**) Around several cores of people have so far been physically displaced across the world due to the construction of dams.

(**ix**) Millions of people living in and around the downstream and away from the dams particularly those depending on natural floodplain function and fisheries also experience serious threats on their livelihoods because of the possibility of large scale depletion and destruction of those resources.

(**x**) So-called attempts for providing compensation and giving scopes for physically displaced peoples for settlement have most of the time result fruitless outcomes.

(**xi**) Resettlement of displaced peoples without proper restoring the livelihoods often result social unrest as resettlement programs mostly focus on physical relocation rather than the economic and social development of the displaced.

(**xii**) Very least restoration of livelihoods of affected communities is seen in response to the higher magnitude of displacement.

6.15.4 Ethical Dilemma with Dams

The following is a list of issues leading to an ethical dilemma for decision makers:

(i) Rights of a small numbers of locally affected population versus fights of large number of potential beneficiaries.
(ii) Conservation of natural resources in order to satisfy the minimum human needs by exploiting those natural resources.
(iii) Standards of international donors and lending agencies versus standards of less developed beneficiary countries.
(iv) Achieving sustainable development is not possible leaving environment totally pristine.

One should accept this hard reality and can only lessen the impacts on the environment.
(v) Good dams are found to be more in numbers than bad ones which by virtue of their shallow depth generally flood large land areas and can generate relatively little power. In most of the tropical countries, these so-called bad dams are also act as reservoirs of several vectors and carriers connected with the diseases like schistosomiasis and malaria especially in the tropical countries.

6.15.5 Possible Solutions to Minimize Problems with Dams

Peoples' perceptions and acceptances of different key decisions and planning pertaining to sustainable management of water and energy resources emerge from recognizing and respecting the rights of indigenous and tribal peoples alongside addressing safeguarding all groups of affected people, particularly, women and other vulnerable groups. The following actions could improve the acceptability and minimize the problems of a dam project.

(i) Avoid and minimize ecosystem impacts.
(ii) Engage in participatory and multi-criteria analysis of development needs and options.
(iii) Ensure that displaced and project-affected peoples' livelihoods are improved.
(iv) Resolve inequities and injustices, with an aim to transform project-affected people into beneficiaries.
(v) Regular monitoring and periodic reviewing are to be conducted.
(vi) Provide proper incentives and sanctions followed by the corrective mechanisms – especially in the area of environmental and social activities.
(vii) Identification, recognition, and inclusion of stakeholders based on their rights in decision-making process pertaining to energy and water resources development.
(viii) Stakeholders, especially the indigenous and tribal peoples, women, and other vulnerable groups, should be provided with the access to information, legal,

and other support in order to make them enable to participate in decision-making processes.

(**ix**) All key decisions taken through agreements and negotiation through the informed participation of all stakeholders should be demonstrated for public acceptance in an open and transparent process with a good faith.

6.15.6 River Regulation and Dams

A varied form lotic biodiversity components including fishes morpho-physiological adaptation against the inundation pressure during to the floods, which represents an usual natural phenomenon of rivers because of higher precipitation during monsoon in different parts of Asia.

In spite of having some inter-annual variation in flood peaks, the flood pulse is not regarded as disturbance in the ecosystem. Instead, striking deviation from the typical pattern of seasonal flow fluctuation is considered as disturbance. This sets the scene for conflict between the needs of humans and of riverine biota.

In such context, keeping aside the requirement of riverine fauna, and also to ensure benefits to human being, several engineering efforts are undertaken based on the baseline information on flow seasonality for capturing, retaining, and storing of water during the time of floods for use of such excess water during the dry period. Such approach has served double benefits to human being like flood prevention and a predictable water supply throughout the year.

6.15.6.1 Conflicts on Regulation and Management of Rivers and Dams: Roles of Nongovernmental Organizations (NGO)

The unpredicted emergence with impressive strength of transnationally coordinated action undertaken by nongovernmental organizations (**NGO**) in the form of social movements has resulted dramatic alteration in the dynamics in and around big dams across the world from the local to the international levels.

Conflicts, contradiction, and debates out of these interactions have been strengthened because of the existing norms, principles, laws, and regulations safeguarding human rights of indigenous peoples and also for the cause of the environmental protection. The steady but gradual institutionalization of resultant opinions following such legislations, norms, and principles into the decision-making processes and procedures within the structural frameworks of the states and international agencies, private sector companies, and other nongovernmental organizations has substantially contributed to the effectiveness of these actors.

However, the transnationally related opposition against the big dams does not follow the same perception in all parts of the world mainly because of two reasons: first, outcomes are most likely to be altered when the local communities through the social movements are likely to be capable of generating sustained mass mobilization in order to alter the outcomes which can be linked to transnational advocacy efforts.

Second, the arguments put forward by the critics of the big dam are likely to be much more effective in democratic institutional contexts. These regimes offer greater opportunities to organize and gain access to decision-making processes and significantly reduce the ability of big dam proponents to violently repress contestation.

These changing transnational dynamics surrounding big dams further highlight a broader transformation that has taken place in the political economy of development. Behind the intensified and transnationalized struggles over big dams lie deep struggles between competing visions and models of development. A range of powerful, transnationally allied groups and organizations (politicians, bureaucrats, landed classes and industrialists, multinational corporations, the World Bank and other international organizations, as well as transnational professional associations of engineers and scientists) have historically involved in promoting dam-related constructions and developments.

The critics of big dam building argue against the powerful lobies having their own interests, hegemonic ideas and dominant institutions, and, adhering rigidly roles against big dam projects. The vision that legitimized and naturalized particular processes and outcomes of dam-related development is being contested by a novel set of transnationally allied actors: previously marginalized but increasingly mobilized grassroots groups and social movements along with rapidly proliferating nongovernmental organizations promoting social justice, human rights, cultural diversity, and environmental preservation, among others.

Such anti-dams movements have necessitated to undertake alternative vision of development that advances bottom-up and participatory processes directed toward socially justifiable and ecologically sustainable outcomes. Presently the conflicts among different competing actors with their respective visions of development have been more vividly displayed than in the intensified transnational contestation over big dam projects which have been projected contrastingly as examples of modernization and destruction, as progress and injustice.

6.15.6.2 Big Dams and Political Economy: Global Perspectives

The transnational political economy of development has been undergoing striking transformation over the last **100** years because of the large-scale constructions of big dams in an escalating pace all over the world. This pace of development is being reflected from the fact that around **600** big dams are supposed to have been constructed mostly in Asia and Africa during**1900**s.

By **1950**, the number of such big dams reached to **5000** in the year **1950** and approximately **45,000** big dams by the year **2000** across the world. The World Bank, which soon emerged as the premier multilateral development agency, took the lead in supporting the construction of big dams across the third world. Promotion of comprehensive river basin planning was also taken up in earnest.

Since that period, by one estimate, the Bank lent over **$58** billion for more than **604** big dam projects in **93** countries. Of the **527** loans made by the Bank for big dams, more than **100** were the largest made to the borrowing country at the time of approval. Despite the estimated more than **US$2** trillion spent on big dam and major river valley projects over the last century, approximately one billion people currently do not have adequate supplies of water.

Another estimate showed that by the year **2025**, **3** billion people living in **52** countries would suffer from water stress due to acute shortages of this precious life-sustaining resource. However, nearly **40%** of the world's river basins shared by two or more countries invite intensified frictions between the states over sharing water resources.

As water is considered as the top of the global agenda, conflicts over water have reemerged as a central concern across the globe. The share in world energy consumption held by developing countries is expected to continue to rise from the current **25%** to over **40%** by **2010**. In anticipation of this growth, third world governments of the third world have focused more to increase the attention of governments to on the water based energy sector.

Despite the heavy investments on power projects and increasing private sector involvement in the sector, however, there are still more than **2** billion people in the world without stable sources of electricity. Such shortfalls, exacerbated by the decline in hydropower big dam building and increasing concerns about the contribution of fossil fuel energy generation to global warming, present increasingly potent transnational political challenges.

Given the powerful set of big dam interests and institutions, along with the tremendous need for water and power around the world, the rapid decline globally over the last quarter century in the rate of big dam building is especially puzzling. The number of major dams completed over time similarly declined: during the **1970**s, **93** of these mega-projects were constructed, while approximately **25** were built in the **1990**s.

Three main types of arguments can be offered to explain this puzzling trend:

1. The decreasing availability of sites for big dam building to account for the falling completion rate around the world.
2. Most (**95%**) of big dams are concentrated in **25** countries in which more than **100** have been built, while less than **2%** are spread over the more than **150** other countries of the world where sites are still readily available.
3. Only slightly more than **10%** of the world's technically available hydropower potential has been developed by energy industry estimates.

6.15.7 Rationality and Present Status of Dams in Asia

As many Asian rivers drain degraded and deforested catchments, the desire to limit peak flows by trapping flood waters behind huge dams is understandable. The conflict between human desires to limit or control flows and the requirements of the ecosystem for natural or semi-natural flows is heightened in Asia by high population densities that place severe constraints on the preservation of riverine biodiversity.

The recent trend in Asia has been towards the construction of more and bigger dams. Approximately **65%** of large dams (**> 15 m** tall) are in Asia (63); China has almost half of these, including **10** major dams (**> 150 m** tall). India (second in Asia and fifth in world ranking) has more than **100** large dams and **7** major dams.

The Mekong has vast potential hydroelectricity-generating capacity, and, in **1994**, the Mekong Commission (an autonomous coordinating committee set up by three riparian states) identified **12** sites for dams (most with planned outputs **>10,000 MW**) along the river mainstream in Laos, Thailand, and Cambodia. A predictable result of these energy generation from the dams is expected to change natural flow variability which in turn impose threats on the fauna and flora.

This averaging of flows is significant because ecological responses to environmental change have appeared to be nonlinear with fish breeding and migrations. Mainstream dams change the timing and extent of floodplain inundation and, in combination with altered flow and temperature regimes, are supposed to suppress fish breeding.

6.15.7.1 Dams, Democracy, and Development in India: Perspective of Environmental Movements

The conflicts, contradictions, conflicts, and debates over big dams in India were emerged, grown, and intensified since the early **1970**s which were ultimately led to develop various anti-dam struggles. Public criticism of the unfulfilled benefits and spiraling costs of big dams in India had mounted and contributed to both the formation of a broader anti-dam movement domestically as well as the transnationally allied opposition to big dams around the world.

The critics of India's big dam building practices, based on the conflicts and debates on Tehri and Narmada Projects, lobbied foreign governments and international development agencies for the withdrawal of financial and technical support for these projects during the **1980**s, in conjunction with the formation of various transnational anti-dam campaigns. Big dam building has emerged as a politicized development activity against the peoples and environment in India during the 1980s as an outcome of growing public debate coupled with the mounting struggles leading to the emergence of transnationally allied opposition.

Three years later, former federal Secretary of Water Resources, Mr. Ramaswamy, Iyer wrote in a widely read article in the year **1989** the following:

> "We should certainly accord priority to the utilisation of the potential already created, the reclamation of the potential which has been lost through misuse, and a vast improvement in water management. We should also place a much greater emphasis than in the past on minor irrigation, which calls for less immediate investment, promises quicker results, and presents fewer problems . . . considering the heavy costs (financial, human, social and environmental)

involved in large-dam projects, we have to be highly selective and extremely cautious regarding approvals to such projects."

This was a sharp contrast of the stand of Mr. Iyer, who, in the year **1987**, shouldered the main responsibility to convince the then Prime Minister of the Government of India, Mr. Rajiv Gandhi, to grant an environmental clearance so that construction could begin on the controversial Sardar Sarovar major dam component of the larger Narmada Projects. The assemblage of several pro-environmental personalities, Non Governmental Organizations from different parts of India and even from other countries during this period (late 1980s) clearly spurred the formation of a broader anti-dam movement in India. with the subsequent joining and involvement of prominent scholars, activists, critics, and leaders of struggles, including Sunderlal Bahuguna from the anti-Tehri campaign and Medha Patkar from the anti-Narmada campaign. The entire mission was organized with the leadership competence by the renowned Gandhian Baba Amte, who himself had earlier led the anti-Subarnarekha campaign.

As a result of their discussions, the participants proclaimed the following **Appeal to the Nation**: Around eighty of us met . . . to express our grave concern about the devastation caused by big dams. We came from different parts of the country, all united by a common resolve – to ensure that people were no longer denied their basic rights over natural resources. We affirmed that the nation's rivers are the cradle of our civilization and that they cannot be strangulated to meet the needs of the exploiting class within society. The issues raised by the construction of big dams challenge the very concept of the present pattern of growth, unquestioningly adopted by our planners. Nothing less than the survival of life itself is at stake for very many or our people, and time is running out rapidly. We appeal to the Nation to halt all big dams, here and now.

Anti-dam struggles and the broader anti-dam movement have thus not only campaigned against the construction of big dam projects, they also promoted different activities, policies, and strategies, in respect of water and energy, forests, and resettlement with a transparent vision of the propeoples and proenvironment development for India.

Finally, the anti-dam movement became one of the leading forces and constituent elements in the growth of a broader sustainable human development movement in India which by building a linkage of anti-dam actors with environmental, tribal, lower caste, women's, human rights, and other like-minded groups established in the National Association of People's Movements (**NAPM**) in the year **1993**. The **NAPM** was dedicated to the peoples for developing a powerful, nonparty political force around which the thousands of domestic nongovernmental organizations that proliferated since the **1970**s could unite with historically marginalized social groups and initiated with considerable strength people's movements to promote an alternative vision of development for India.

However, three trends that became more prominent during the **1990**s did begin to counter the strength and undermine the effectiveness of big dam opponents, sustainable human development proponents, and their transnational allies in India.

The first was the progressively more active organization and mobilization of pro-dam actors, an indication in itself of the changed dynamics of development in India. These have included such groups as rich farmers and middle classes; technical, professional, and bureaucratic elites linked to big dam building; private sector companies who increasingly wanted to seize new profit-making opportunities linked to these projects; as well as politicians who were dependent on these groups for their political survival and success. These actors also strengthened their transnational linkages to like-minded groups from international professional associations, such as the International Commission on Irrigation and Drainage; allies in donor agencies, like the World Bank; multinational corporations; and nonresident Indians living abroad.

The second trend was the progressive adoption of neo-liberal economic policies and the related privatization and liberalization of the power and water sectors similar to most developing countries during this period. The policy and institutional changes that had been promoted, and to a certain extent achieved, with respect to big dam building by opponents had not focused on the increasing private sector involvement in big dam critics thus increasingly faced less conducive political opportunity structures than if public authorities were the lead developers of these projects. But as the conflicts over the Maheshwar Dam component of the Narmada Projects that domestic Indian private sector firm S. Kumars took over building demonstrated, if foreign corporations are actively involved, then transnationally allied opposition linked to domestic mobilization is likely to increase and make the building of a big dam extremely difficult in India.

The third trend was the growing strength of Hindu fundamentalist religious movements and right wing political parties within India. Extremist organizations, such as the Rashtriya Swayamsevak Sangh (**RSS**), Vishwa Hindu Parishad (**VHP**), and others that are collectively known as the Sangh Parivar in India increasingly and successfully "**Hinduised**" marginalized groups such as tribal adivasis and lower castes by offering different kind of help and also spreading successfully religious ideology. Utilizing democratic political opportunity structures and winning the cofidence and perception of the local peoples the changing dynamics of big dam building was resulted with the gradual but sustained decreased in the intensity of anti dam movement.

Nevertheless, the period in between **1970**s to the **1990**s, the previously marginalized, domestic subaltern groups, such as poor peasants and tribals, became progressively more aware, empowered, and organized in order to mobilize for the substantial environmental reform, towards the construction of big dams and to lobby for greater access to India's democracy and greater inclusion in India's development. The mobilization by these subaltern groups was ardently and consistently supported by the tremendous proliferation of activists and nongovernmental organizations committed to promoting transparency, participation, cultural diversity, social justice, and environmental sustainability. The resultant coalitions and networks were transnationalized through links with like-minded foreign allies and through legitimation by the growing domestic institutionalizing of globally spreading norms. The in-depth historical and ethnographic analysis of Indian's Narmada projects are supposed to provide further evidence that these combined factors often result in the reform, stalling, and/or halting of big dam building. They also have been shaped by and contributed to the transformation in the transnational political economy of development in India, around the world, and at the international level.

6.15.8 Dams: Sustainable Management in View of Ecological Impacts

6.15.8.1 Historical vs Present: Ecological Impact of Dams Construction

Although, historical records have revealed the initiation of dam construction started around **5000** years back as evident by one of the oldest dams, the Sadd el-Kafara dam in Egypt, which was built for flood protection. However, majority of the existing dams in different parts of the world have been constructed after the Second World War keeping pace with increasing people's demand for gearing up the economic development.

In the present world, around **6000** planned large hydropower dams (>**15** m height) along with an uncountable number of small dams are present across the world (Zarfl et al. 2014). The prime harmful impact of dams concentrates on downstream flows which are mainly altered by large dams, e.g., there are **654** reservoirs with storage capacities of **0.5 km^3** (Lehner and Döll 2004, Lehner et al. 2011).

Almost **15%** of global annual river runoff are being stored within the dams, imposing several and severe ecological impacts (flow regulation, alteration of sediment transport, fragmentation of habitats, loss of biodiversity) on **48%** of rivers globally (Likens 2010). However, creation of modern impoundments have sequestered approximately **25%–30%** of pre-disturbance sediment flux all over the world, the impacts otherwise would have been double, had all planned dams be constructed by 2030 (Likens 2010; Grill et al. 2019).

This has become more prevalent in the regions with expanding economies which demand for an utilization of extensive unexploited river reaches, such as in the country like China in the Southwest region of which around **130** major dams have been recently constructed (Lewis 2013) which account for more than half the newly built dams since 1950 worldwide (Wang and Chen 2010).

6.15.8.2 Definitions and Significance of Dams and Reservoirs

"A dam refers to a physical structure retaining the water by creating a reservoir and also act as barrier that obstruct the flow of water from the headwater to downstream. Reservoirs, the large bodies water are designated also as "impoundments" which are built for some specific community needs:

- Drinking, industrial, and cooling water supply
- Hydropower generation
- Agricultural irrigation
- Regulation of the flows of rivers and controlling of the floods
- Navigation
- Recreation and fisheries

While dams being the symbols of the negative attitudes of human beings towards rivers and river basins, which considerably modify the physiography of watersheds, and significantly alter their physicochemical characters which are reflected by the biological responses.

At the early stages after its formation of the reservoir, water quality exhibit changes slowly but steadily until the arrival of ecological stability and balance among different structural components of the aquatic ecosystem (Straskraba et al. 1993). Besides, based on the form, location, and mode of operation of reservoir, limnological characteristics of reservoir vary in accordance with the sizes, structure, depth, location, and mode of its utilization and operation.

Reservoirs follow a succession of different eco–geo–biological conditions such as:

1. Alteration of physicochemical.
2. Changes in species composition and ecodynamics of primary producers.
3. Modification in the pattern of assemblages of consumers within the community, especially invertebrates and fish (Petts 1985). On achieving ecological stability, reservoirs also encounter new disturbances by the occurrence of floods, dam operation, etc.

Reservoirs not only affect the normal ecology of inundated parts of the rivers but put constraints and hindrance of upstream fish migration and downstream sediment transport with water flow. The magnitude of the intensity of such impacts proportionately varies with the location of the dam and size of reservoir (height of dam, volume of reservoir).

Water residence time, being an indicator of the average water retention period within the specified enclosed area an aquatic system, acts as a key parameter controlling the system's biogeochemical pathways. The water residence time serves as fundamental for multiple and complex processes (fluctuations of stored water level, capture and release of sediments, seasonality of downstream flow patterns) in reservoirs (Rueda et al. 2006). The major impacts of reservoirs on the river ecosystem are summarized by Rueda et al. (2006) which are as follows:

- Interruption of the continuity of river flows both at longitudinal and lateral directions influencing fish migration and transport of sediments and nutrients
- Siltation of river bed and clogging of interstitial spaces of the sediments
- Bringing homogenization of habitats
- Developing incision of downstream river bed

- Alteration of water exchange processes in the river bed and groundwater exchange
- Alteration in downstream flow and water quality parameters

6.15.9 Transforming Rivers to Reservoirs

Damming of a river involves drastic a process which result in the creation of a completely new ecosystem (Baxter 1977). The environmental impacts are thought to be inherent with any impoundment due to the fundamental changes of the hydrology associated with flow patterns and geomorphological structures of the river.

Flows of water not only represents the main force behind freshwater ecosystems but also determine geohydrological structure, matter and energy fluxes, biological productivity, and distribution and function of biota (Baxter 1977; Poff et al. 1997). Consequently, the altered flow regimes and morphodynamic patterns impart far-reaching impacts on the resource availability, including production, biodiversity, and ecological services rendered by of aquatic ecosystems (Nilsson et al. 2005).

A lot of differences exist in between reservoirs and natural lakes with respect to hydrological, limnological, and ecological dynamics. A longitudinal hydrological gradient from the dam (lentic or lacustrine zone) to upstream reaches (riverine zone) is developed based on the size and shape of the reservoir exhibiting intermediate characteristics in middle stretches (transition zone, with lentic and lotic features) (Kimmel and Groeger 1984).

Different stretches of a large reservoir is characterized in having different sediments profiles, e.g., the riverine section of the reservoir is endowed with coarse sediments, while fine sediments (sand, silt) and particulate organic matters (**POM**) are deposited in the lacustrine zone.

Depending on the structural and physical characteristics within the reservoir, development of anoxic water on the sediment layers often occur as a consequence of a chain wise ecological processes such as stratification, deposition, and decomposition of organic materials (Agostinho et al. 2008); thermal stratification (epilimnion, hypolimnion, thermocline, light penetration etc.), alteration in the biological production systems (autotrophic, heterotrophic) and modifications of the structure and function of food chain.

Disconnection of the reservoir hydrologically from the floodplains because of the association and connectivities of dams with construction of lateral dams or leeves, leads to, limited or abandoned inundation and reduced interchange with the groundwater which in turn lower the chances of recolonization, both lateral and longitudinal. As a result, the new ecosystem is colonized by those species that inhabited the original river and now have developed the adaptability to adjust and flourish in the new ecological set ups (Agostinho et al. 2008).

Non-migratory, eurytopic species dominate the lacustrine zone of reservoirs because they require not much of resources, both living and nonliving from their habitats. Development of lentic environment, within the reservoir, takes place only after its spatial fragmentation which in turn leads to cause retardation of flow of water and the decline of critical habitats (spawning grounds) and the drastic reduction of the abundances of the migratory and rheophilic species. Consequently, lotic fish species are replaced by lentic ones and which start dominating the reservoir fish communities (Zhong and Power 1996). Deposition of fine sands in the reservoir leads not only to the reduction of the depth of the reservoirs but also clogging of the river bottom which in turn affects aquatic communities of the hyporheic interstitial fauna (Ward et al. 1998). As a consequence, the ecological status of reservoirs, especially within the stretch of lacustrine section, is denoted as poor or bad (**EU** Water Framework Directive, Ofenböck et al. 2004). In contrast, the energy and matter fluxes in the riverine section are based on input of allochthonous matter regulating the energy and matter fluxes after being triggered by photosynthesis and inner cycling.

Allochthonous organic matters such as dissolved organic matter (**DOM**) and particulate organic matter (**POM**, trigger the riverine ecosystem functioning after being directly utilized by consumers and indirectly by bacteria and fungi associated with decomposing organic matters. In addition, algal growth and primary productivity in the fresh water habitats are regulated by the water residence time, mineral components (dissolved mineral matter (**DMM** and light conditions (particulate mineral matter (**PMM**,); and particulate organic matter (**POM**) (Herzig 1984).

Littoral zones of the reservoir possess higher biodiversity because of the greater availability of nutrients and heterogeneity of feeding resources, shelter, and habitats (Agostinho et al. 2008). On the other hand, however, the distinct fluctuations of the ecological variables in the littoral zone impose frequent stresses to fauna and flora.

Higher intensity, magnitude, and frequency of water level fluctuations create **dead zones** along the shore lines of the reservoir. Conversion of rivers into reservoirs results in the transformation of the former fluvial habitat into the new lentic ecosystem lake-type systems, but, depending on the type and mode of dam operation, reservoirs experience disturbance by artificial water level fluctuations, drawdowns, and floods.

Downstream effects and impacts are equally or even more damaging to aquatic fauna (blockage of migration routes for some fish species), and the retentions of sediments and nutrients affect primarily water flow dynamics, redistribution of river discharge from the impoundments, influence several hydrological attributes, such as intensity, amplitude, duration, and frequency of floods and the structure, dynamics, and functioning of river ecosystem especially at downstream.

6.16 Mitigation Measures: An Integrated River Basin Management Approach

Reservoirs in the dams facilitate system shifts on running waters, making reestablishing pre-damming conditions impossible. Therefore, the objective of mitigation effort is to improve the ecological health of the river body by reducing if not possible by removing the impacts. In such context, mitigation measures mainly concentrate on ensuring habitat improvements of the riverine section of reservoirs (head section) and on river sections located at up- and downstream of the reservoir.

Major thrust is made on the reestablishment of longitudinal continuity within the habitat by enabling fish migration through fish passes. Downstream mitigation measures involve environmental flow regulations and sediment transport by adopting sediment management.

6.16.1 Reestablishing Longitudinal Continuity: Concept of Ecological Trap

An acceptable form of restoration measure for dams requires the development of conditions for the implementation of fish passes in order to enable the migration of upstream fish, often by negotiating the multiple dams. The upstream fishes generally start for a long migration during the reproductive season in search of habitats suitable for spawning and providing the young scopes for healthy growth and development.

After reaching the adult stage, the adult fish start migration back to their downstream habitats where eggs and larvae are tranported more downstream in the main rivers by currents but such movement to the downstream is hindered by the dams and of such movement to the downstream is hindered by the dams and reservoirs. All such incidents result very poor recruitment for riverine fish populations downstream of the dams.

Reservoirs act as an ecological trap by usually proving unsuitable habitats for juvenile fish for their settlement because of four of the following conditions (Pelicice and Agostinho 2008):

1. The fishes are forced to enter the reservoir by attractive forces directing the movement of fish to ascend the passage.
2. Owing to unidirectional migratory movements of fish from the upstream to downstream.
3. The poor ecological conditions above the passage without having spawning grounds and nursery areas prohibit fish recruitment.
4. The ecological conditions below the passage provide proper structure for recruitment.

When these conditions exist, individuals of migratory fishes move to the habitats with poor environmental quality which in turn decrease the fitness, imposing survival threats to the fish population.

Based on current and proposed scenarios, in such context, considering the existing ecological conditions and status in respect of river regulation, it is concluded that conservation of migratory fish poses real difficulty and becomes complicated (Pelicice et al. 2014).

6.16.2 Sediment Management

The main objective of of sediment management should include to make flushing of the sediment of dams, sediment bypass, and sediment augmentation within the downstream of reservoirs so that proper transport of sediment in order to transperacy of water of the dam (Kondolf et al. 2014).

Such mitigation strategy must maintain a balanced relationship between the capacity of reservoirs and the mean annual water and sediment inflows. The entire venture includes the following:

1. Sediment sluicing: the aim of sediment sluicing involves a reduction in water level and also to ensure the sediment-loaded water prior to deposition in the impoundment.

Through the sediment sluicing, a reduction in the volume and level of water loaded with higher amount of sediments l in the impoundment takes place by opening gates.

2. Turbidity venting controls low level gates or deep sluices for facilitating the sediment loaded water to **flow** along the bottom of the reservoir.

3. Sediment flushing is the reduction of reservoir levels to pre-impoundment levels, for enabling the **river** to erode deposited sediments.

4. Bypass structures are tunnels, constructed canals, or existing river channels, which can be used to pass higher sediment-loaded water and bed load around an impoundment, in order to ensure decreasing of the trapping of sediment. This provides a benefit towards the maintenance of the seasonality of sediment delivery to the downstream river.

5. Reintroduction of dredged material is mainly for reintroducing excavated or recovered material back into the downstream channel (Danube River downstream of Vienna, Austria, and Rhine River at Iffezheim, Germany).

Most reservoirs possess a capacity of mean annual flow ratio of between **0.2** and **3** and a life span of **50–2000** years depending on the sedimentation within the reservoirs. However, during sluicing or flushing of sediment the capacity mean annual flow ratio becomes less than **0.03**, during floods. Flushing is a sustainable operation, and a long-term equilibrium storage capacity can be reached through the sustainable flushing operation (Basson 2004).

6.16.3 Reservoir Flushing: Impacts on Faunal Components

Newcombe and Jensen (1996) classified the effects of reservoir flushing as:

1. Lethal effects causing high-to-low mortality, and high-to-medium habitat degradation.
2. Lethal effects along with paralethal ones result in high predatory pressure and prolonged hatching period of larvae.
3. Sublethal effects lead to develop reduction of growth, fitness, and feeding of fish and also develop disturbed homing effect coupled with physiologic stress.
4. Generates behavioral effects such as emigration and active and passive drifts.

While behavioral effects are mainly reversible and limited to the duration of exposure, physiologic changes have a more long-term adverse consequences depending on the intensity of impacts which also depend on a number of parameters such as concentration and duration of exposure, the size and texture of particles, water temperature, concentration of toxic substances, density, volume and flow of water, physical and chemical properties of water, etc.

The decomposition of organic matters results in depletion of dissolved oxygen which in turn leads to suffocation of fish and other aquatic animals like benthic fauna. In order to have an assessment, the **ranked effects model** as an innovative tool is applied for quantifying negative effects of suspended solids on fish (Newcombe and Jensen 1996).

6.16.4 Development of River Basin Concept: An Important Contributor for Integration

The river basin concept has a wide application and a long history. The interpretation and the use of the river basin as an integrative concept vary from single-purpose, small-scale development schemes, e.g., of hydropower to large multipurpose development schemes (White 1991, 1996; Wengert 1980). The use of the river basin concept seems to need reinterpretation and specification. Much criticism has been presented to the idealistic use of the river basin concept as a "**natural law**" for water management organization.

On the other hand, increasing water demands and water development calls for integrative river basin development strategies which take into account the changing patterns of hydrological, geomorphological, ecological, biodiversity of the rivers, and river basins. The river basin itself is an ecosystem subject to multiple uses. The geomorphologist, the hydrologist, the social scientist, and the climatologist can all contribute to an ecosystem approach to river basins, but, because these specialists are so bound up with other aspects of the ecosystem, it becomes necessary to have an integrated approach.

The river basin provides a natural boundary to evaluate the ecosystems contained therein. In most ecosystems there is no actual membrane separating system from environment. The ecosystem approaches have brought together natural and human ecology with an interdisciplinary approach to study and analyze the ecosystem processes in the rivers and river basins.

6.17 Decadal Changes of Land Use in the Freshwater Riverine Networks of South West Bengal, India

6.17.1 Land-Use Pattern in the Kansai and Subarnarekha River Basins, West Bengal, India (Figs. 6.1, 6.2, 6.3, 6.4, 6.5, 6.6, 6.6, 6.7, 6.8, 6.9, 6.10, 6.11, 6.12, 6.13, 6.14, 6.15, 6.16, 6.17, 6.18, 6.19 and 6.20)

The linkages between land use and the availability and distribution of water resources are complex. The complex hydrological processes have been developed because of the linkages between land use and water resources that transfer net precipitation to river flow and bring forth variations in groundwater recharge in tune with the varying profiles of with topography, soil, hydrogeological properties, and rainfall characteristics (Anderson and Burt 1978; Dunne and Leopold 1978).

To conserve usable water resources, land uses which increase evapotranspiration, or rapid runoff, flooding, or soil erosion, should be minimized discouraged in water-stressed areas. Changes in land use or farming practices that cause runoff, flooding, or soil erosion at the expense of groundwater and summer low flows should also be avoided.

Encouraging infiltrations therefore represents an important objective in the land-use planning which must have an objective for encouraging infiltrations. Catchment-sensitive farming techniques help protecting water resources, by enhancing the infiltration rates through the porous soils and maintaining the water quality by minimizing diffused (non-point) pollution.

Other soil management techniques can also be applied to improve land managers' awareness, including cross compliance requirements and agro-environment schemes with the provision as well as regulation where it is essential. Satellite imageries on land-use patterns in the river basins of Kansai river and Subarnarekha river have depicted a considerable changes in respect of time intervals between 1990 and 2008.

Field observations and other land-use thematic information-based classification of satellite images by supervised techniques have provided information on nine categories of land use and their time series land-use classes changing patterns. From the areal distribution chart, it is observed the forest area in Kansai river basin has been decreased to almost **30%**, whereas in Subarnarekha river basin, such reduction has been found to be **25%** between **1990** and **2008** period.

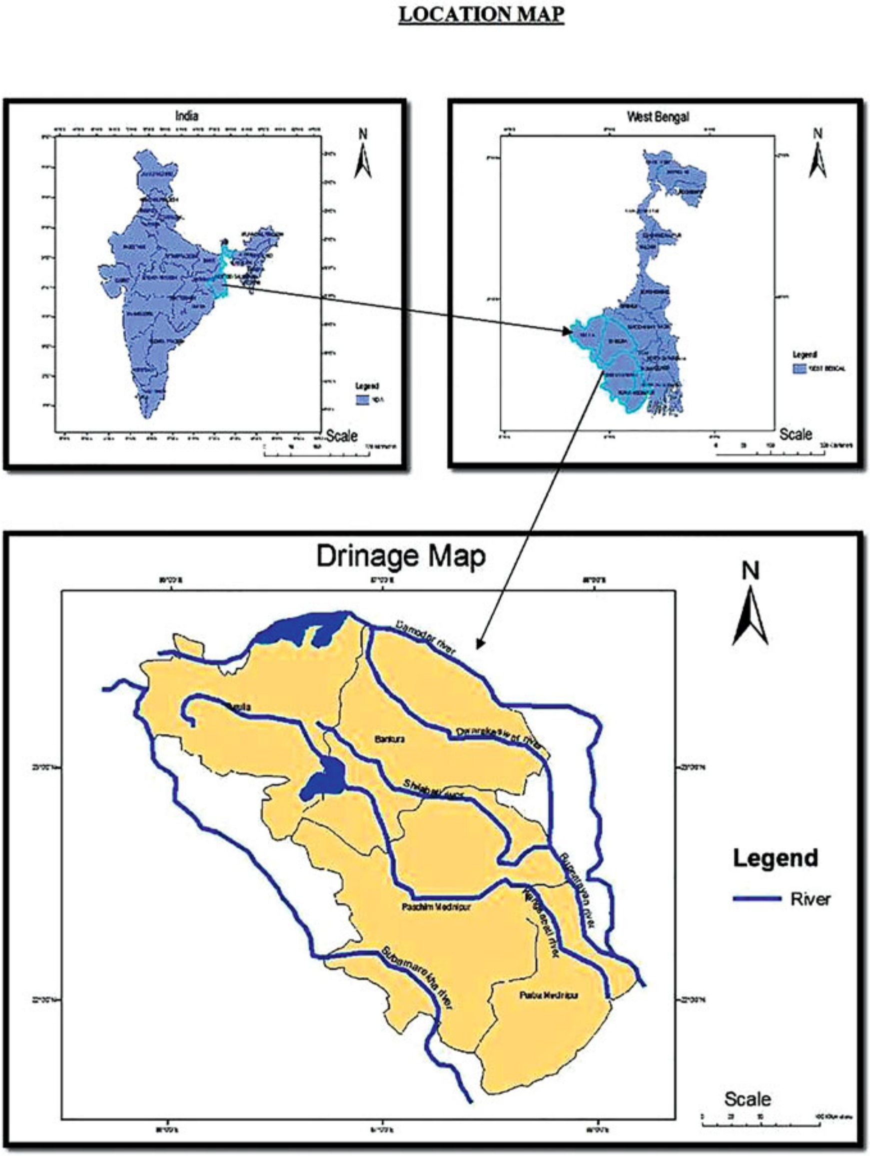


Fig. 6.1 Location map for the eco assessment of land-use changes and sustainability of water resources at selected study areas of South West Bengal, India

On the other hand, areas of scrub land and fellow lands have been increased. So far as the water bodies and agriculture are concerned, the former experienced a reduction of almost **10%**, whereas the latter exhibited an increase of **11%** (Tables 6.1 and 6.2).

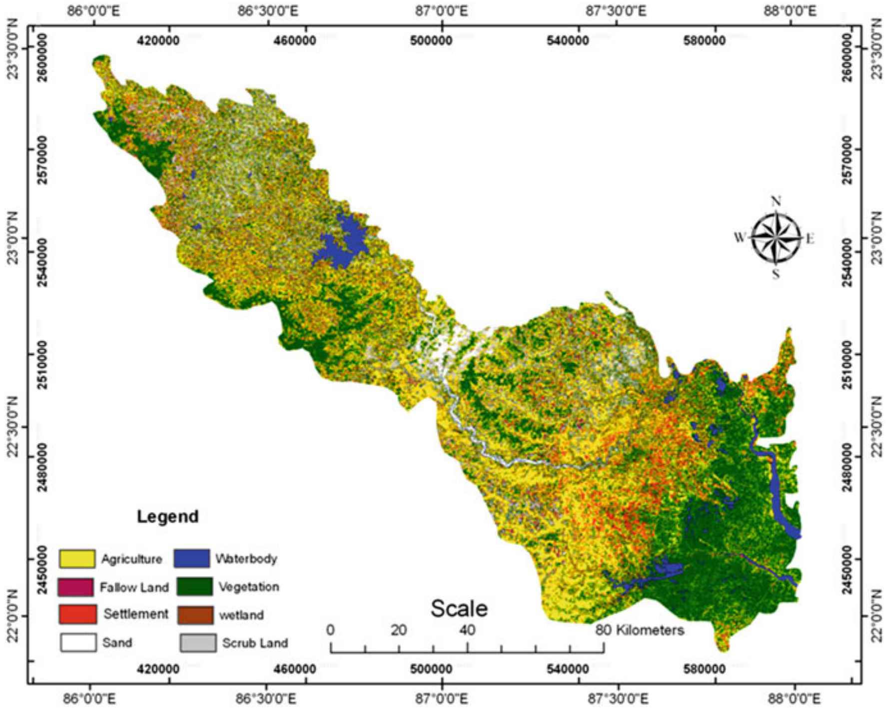


Fig. 6.2 Satellite imageries depicting land-use pattern of Kansai river basin during 1990

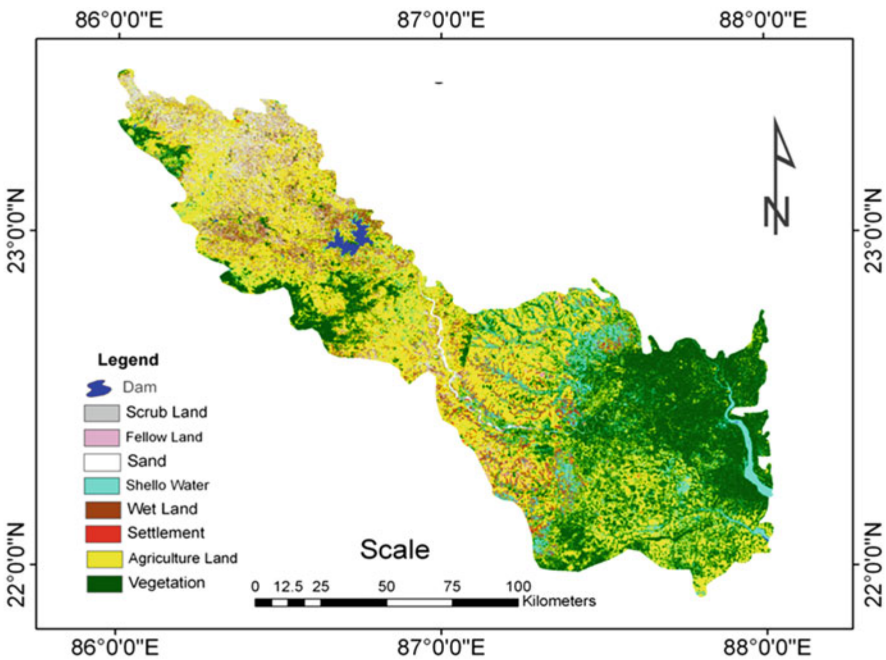


Fig. 6.3 Satellite imageries depicting land-use pattern of Kansai river basin during 2008

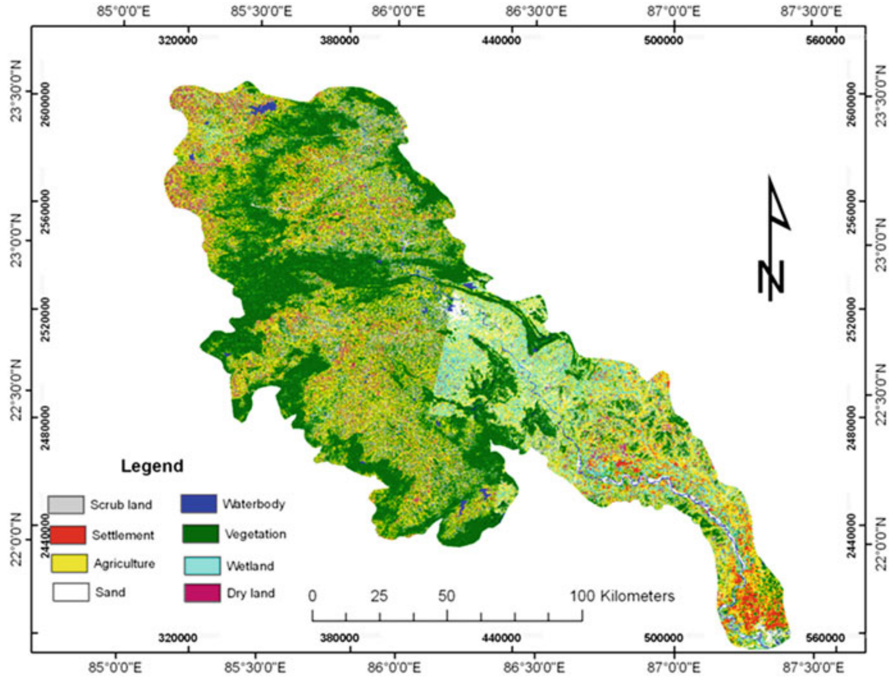


Fig. 6.4 Satellite imageries depicting land-use pattern of Subarnarekha river basin during 1990

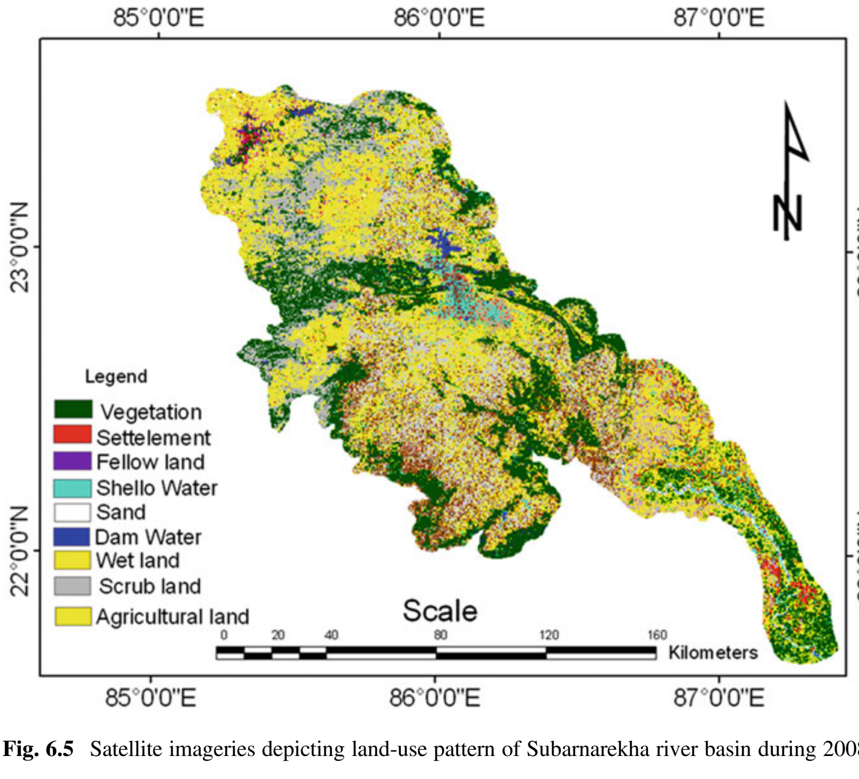


Fig. 6.5 Satellite imageries depicting land-use pattern of Subarnarekha river basin during 2008

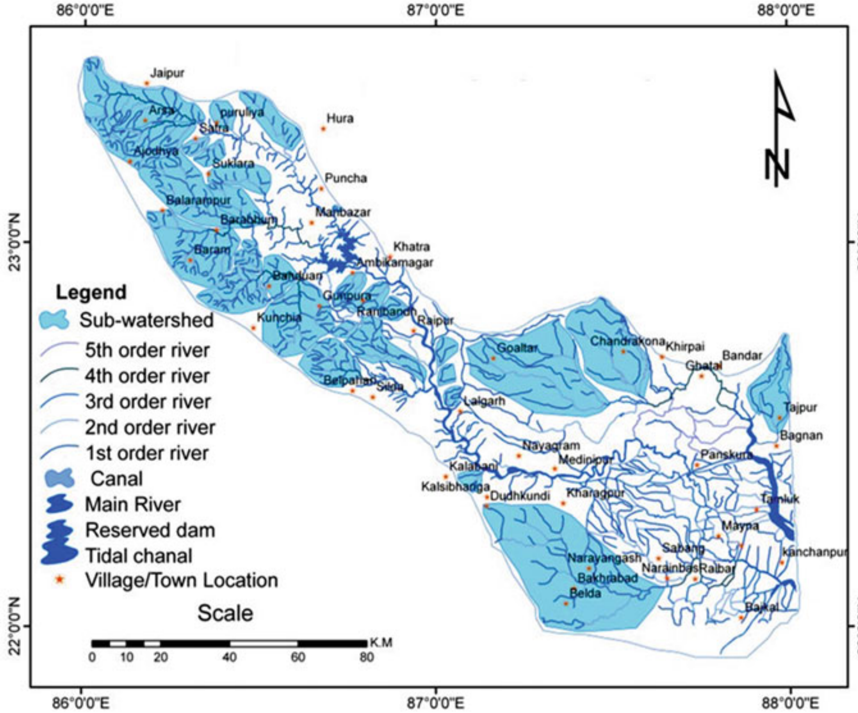


Fig. 6.6 Satellite imageries depicting different stream order at water shade of Kansai river

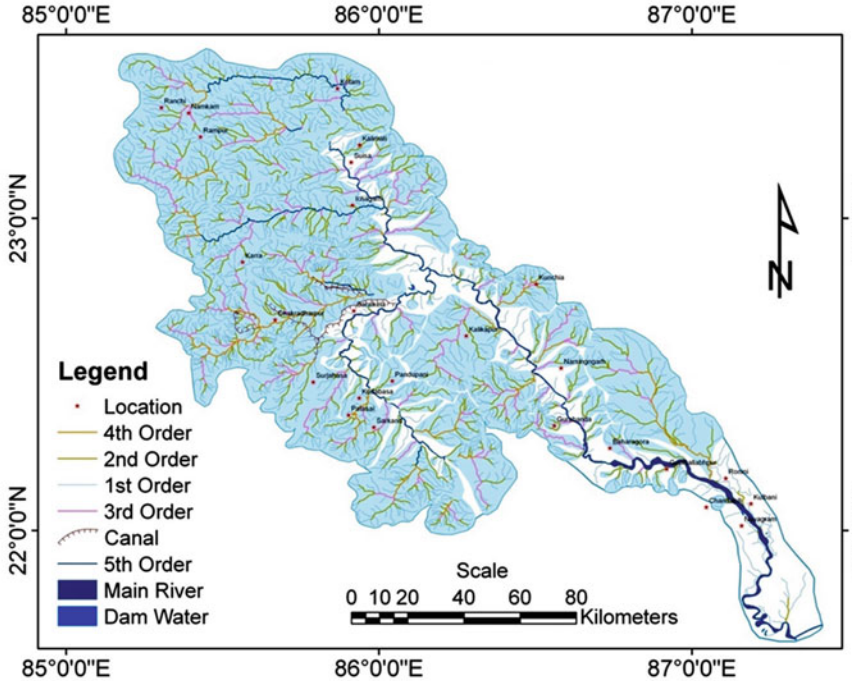


Fig. 6.7 Satellite imageries depicting different stream order at water shade of Subarnarekha river

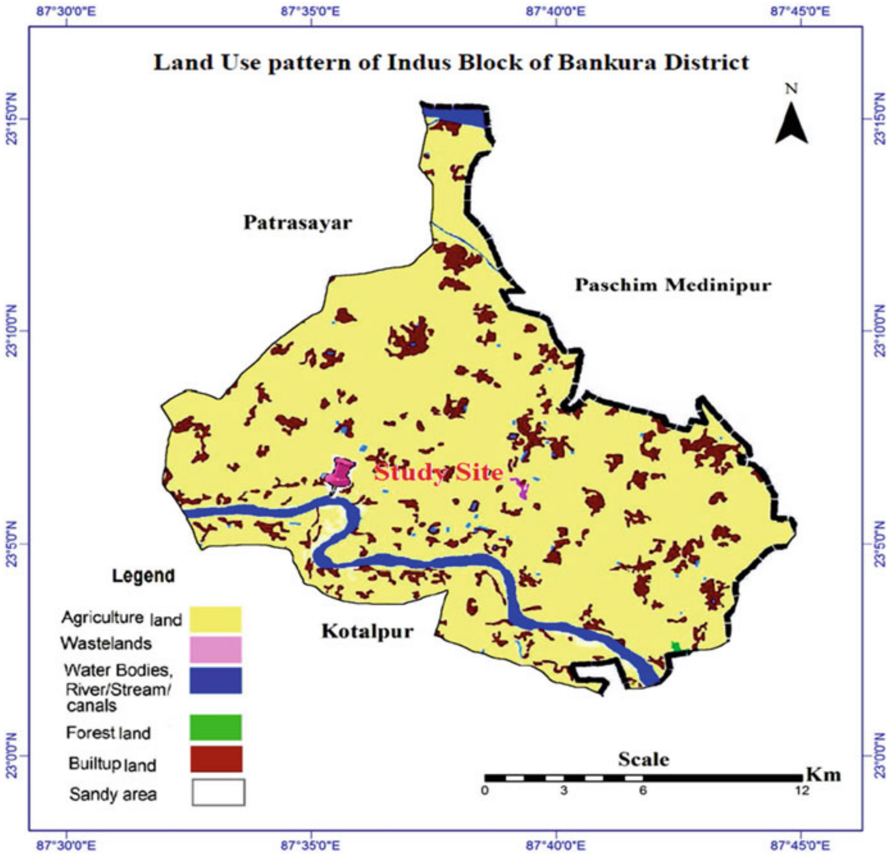


Fig. 6.8 Land-use pattern of particular site (Indus block) at Bankura district along Kansai river

6.17.2 Different Land-Use Patterns

1. **Agriculture**: Cultivation in several districts (Purulia, Bankura, Burdwan(East), Burdwan (West), Midnapore (West), Midnapore (East), Hoohly and Birbhum) of south West Bengal, India, is predominantly mono cropped under rainfed condition with paddy as the primary crop with low fertilizer utilization per unit area.
2. **Animal husbandry**: Animal husbandry sector is considered to be one of the major activities for providing subsidiary income to the rural farming families in the all those districts of West Bengal, India. Moreover, development of this sector is considered very important as a source of supply of essential nutrients to the peoples. In order to cater to the need of the peoples of all these rural districts, around **10** lakhs of cattles, **1.5** lakhs of buffalows, **3** lakhs of goats, **2.5** lakhs of ships, **16** lakhs of fowls, **5** lakhs of ducks are supplied and also maintaining the

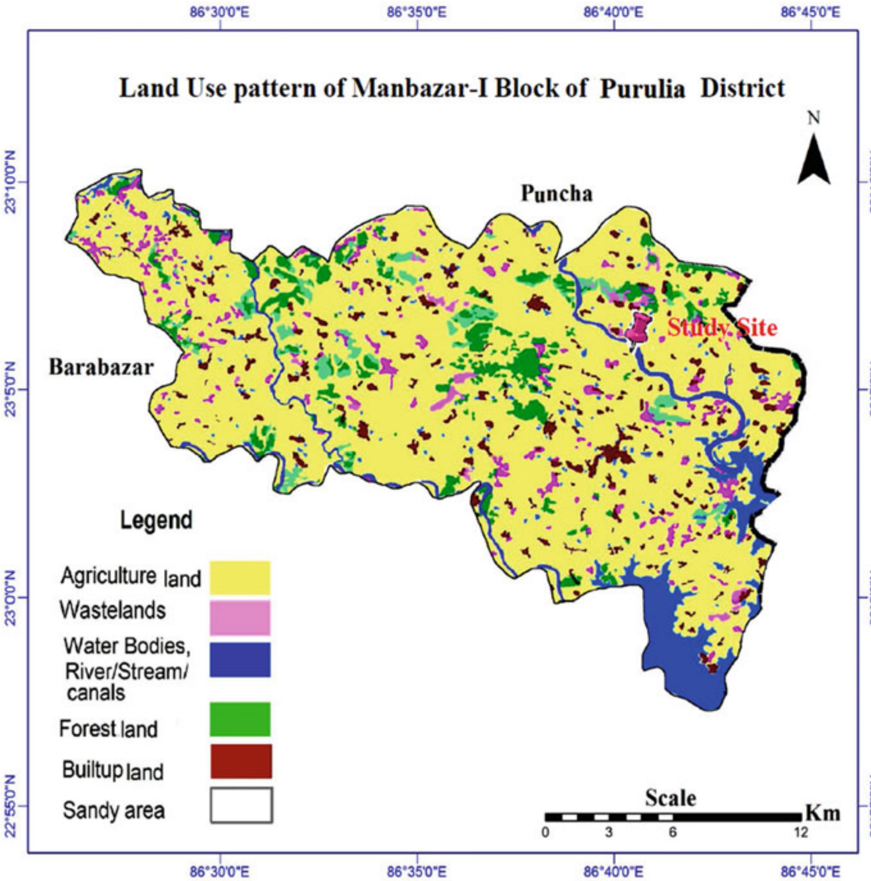


Fig. 6.9 Land-use pattern of particular site (Manbazar I block) at Purulia district along Kansai river

health of those animals more or less **10** veterinary hospitals with proportionate veterinary doctors and supporting personnels are required.

3. **Forest:** The forest types differ spatially depending on many geographical factors like latitude, altitude, rainfall, temperature, relative humidity, slope, and soil. The Department of Forest, Government of West Bengal, India, has divided the forest cover of West Bengal in ten types, and the three major districts [(Purulia, Bankura, and Midnapore (West) of the state of West Bengal, India (Fig. 6.1)] are endowed with tropical dry deciduous forest along with seven others and cover an area of **4527 km²**. (Environment Report, W.B.P.C.B. 2009).

Bankura district is dominated by croplands and deciduous forests as well as plantations, interspersed with fallow lands. The district has a couple of urban settlements, being mostly dominated by rural settlements. The entire district is traversed by three major flowing water channels with one large lentic water body at the southwestern part.

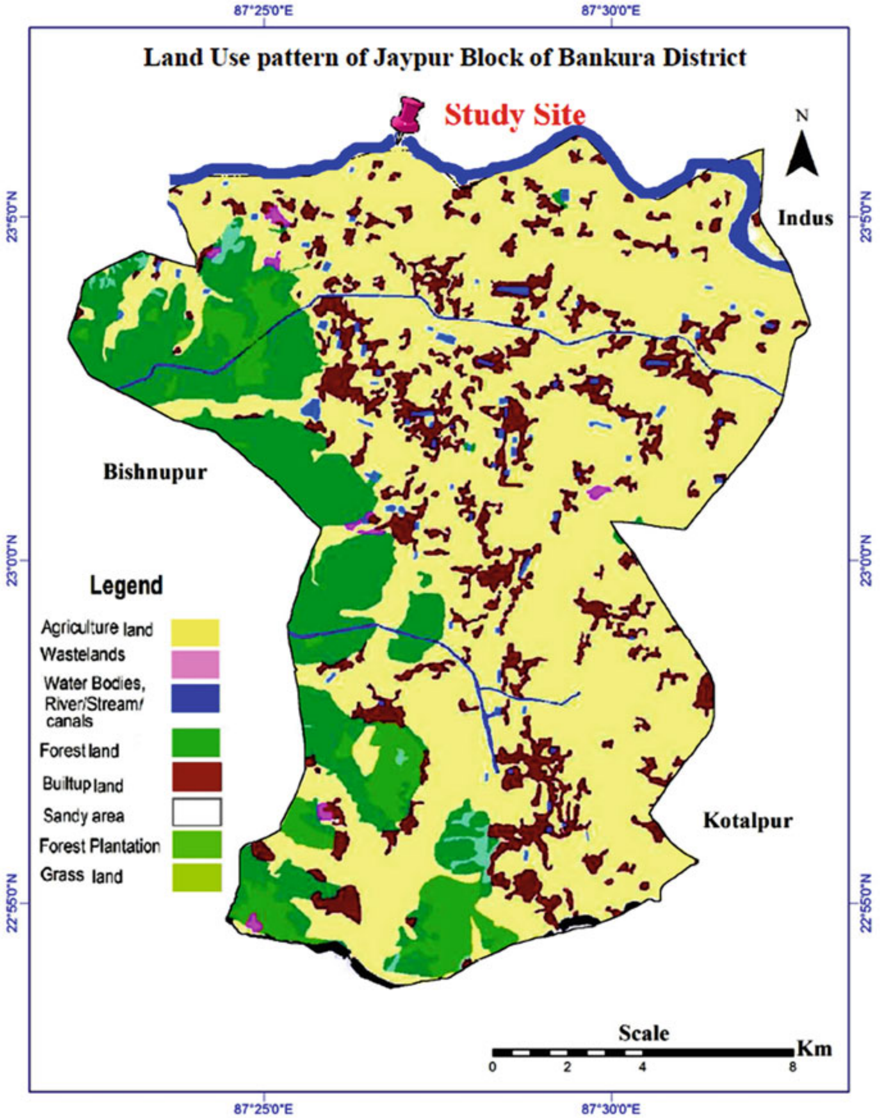


Fig. 6.10 Land-use pattern of particular site (Jaypur block) at Bankura district along Kansai river

Purulia district has alternating fallow lands and croplands with natural deciduous forests occurring as patches in the western and southern parts mostly. Barren scrublands predominate in the northern and central parts of the district. A couple of urban settlements and most of the rural settlements occur in the northern and central parts.

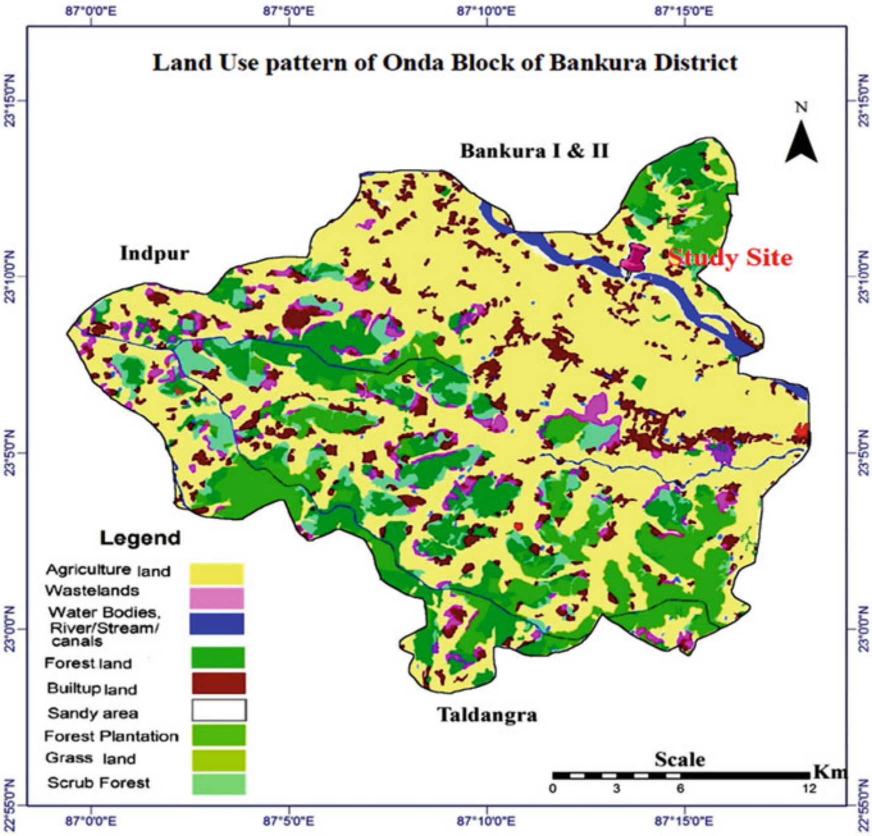


Fig. 6.11 Land-use pattern of particular site (Onda block) at Bankura district along Kansai river

Two lentic water bodies occur in the northern and south-eastern parts of the district. Midnapore (West) has a significant forest cover (both natural deciduous and plantation) on the western part with agricultural and fallow lands dominating the eastern and southern ends. Two important lotic water bodies run through the central and southern parts of the district.

The southwestern part is dotted with barren scrublands where some plantation has been undertaken. The district has more than a dozen urban settlements with the bulk of rural settlements concentrated along the eastern and south-eastern border.

6.17.3 Land Use and Its Impacts on Water Resources

At the catchment scale, changes in land use exert a prime controlling effect on the hydrological processes driving on the fluxes of water and solutes (Howden and Burt

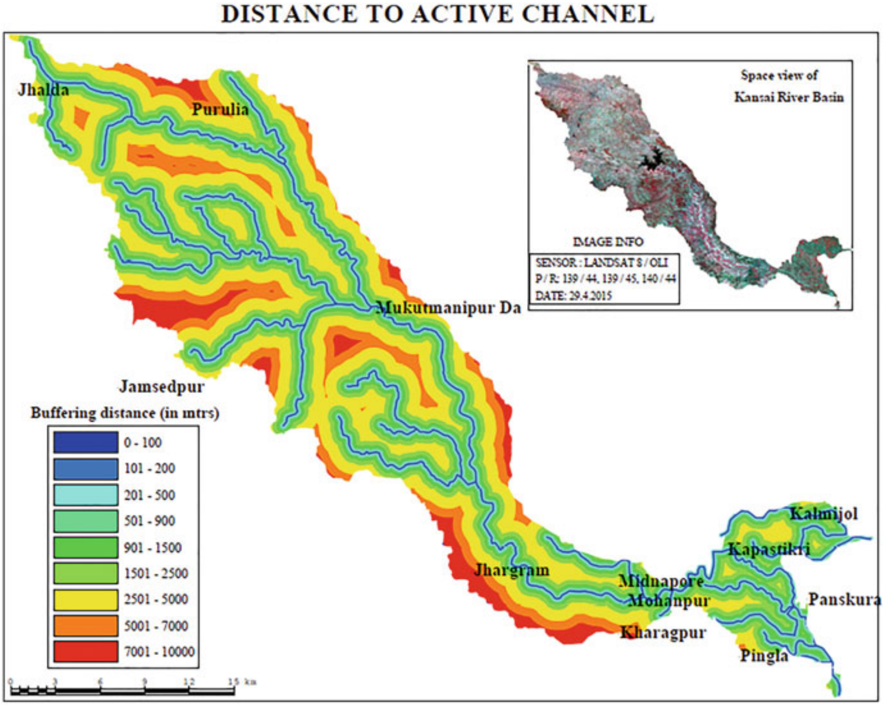


Fig. 6.12 Satellite imageries of channel drainage system of Kansai river basin

2008). Raymond et al. (2008) recently showed that an increase in the discharges from agricultural lands enhanced the bicarbonate and water fluxes in the Mississippi Basin between **1902** and **2008** which were caused mainly by an increase in the discharges from agricultural lands that were not balanced by a rise in precipitation. This has indicated an increase of both runoff rates and chemical weathering due to the land-use eco-management practices. The linkages and interrelationships between land use and land management serve to maintain the ecological health of water resources and result a series of effects as mentioned below:

1. Effects on catchment yield
2. Effects on infiltration
3. Effects on dissolved organic carbon and water color in upland drainage waters
4. Effects on nutrient transfer to rivers and groundwaters

The ecological consequences of afforestation on runoff yields in the upland reservoir catchments of United Kingdom (**UK**) has long been focused as an example for developing any eco-management strategy of rivers (Neal 1997). Mature forests tend to reduce peak flows via two mechanisms:

1. High rates of evaporation of canopy interception
2. Increased water storage capacity of soils under trees (Robinson and Dupyrat 2005)

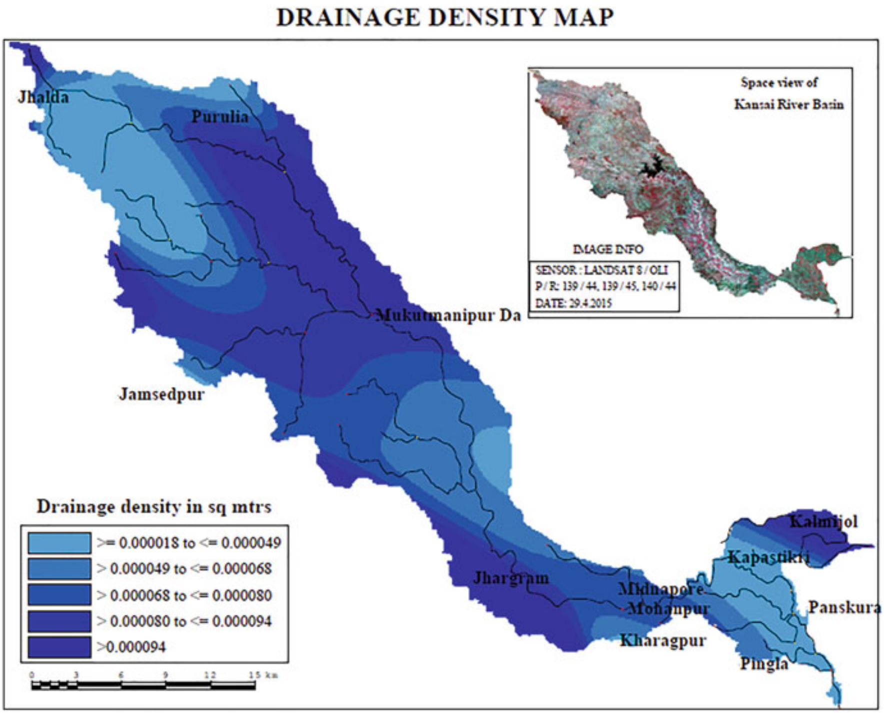


Fig. 6.13 Satellite imageries of drainage density in (sq M.) of Kansai river

Calder (2007) suggested that afforestation impart effect on small catchment scale, but attenuation effect has become small- for large-scale events in large afforested catchments. Stephens et al. (2001) advocated that the expansion of cultivation of energy crops would increase evapotranspiration and thereby impose damaging impacts on lowland rivers and groundwater resources.

6.17.4 Infiltration Rates and Land-Use Pattern

It has been observed that agricultural practices impart significant effects on the scales, intensity and magnitude of floods (Holman et al. 2003; Howden, & Burt 2008; Howden and Deeks 2007 on soil morphology and runoff processes but also contribute to reduce the water storage capacity of the land, increase the runoff rates and the risk of flooding (Holman et al. 2003; Howden and Deeks 2007; O’Connell et al. 2007).

Increased runoff, and hence decreased infiltration, reduces recharging of the aquifers, and hence groundwater is reduced by increased runoff and decreased infiltration resources (Rauzi and Smith 1972; Greenwood et al. 1997; Nguyen

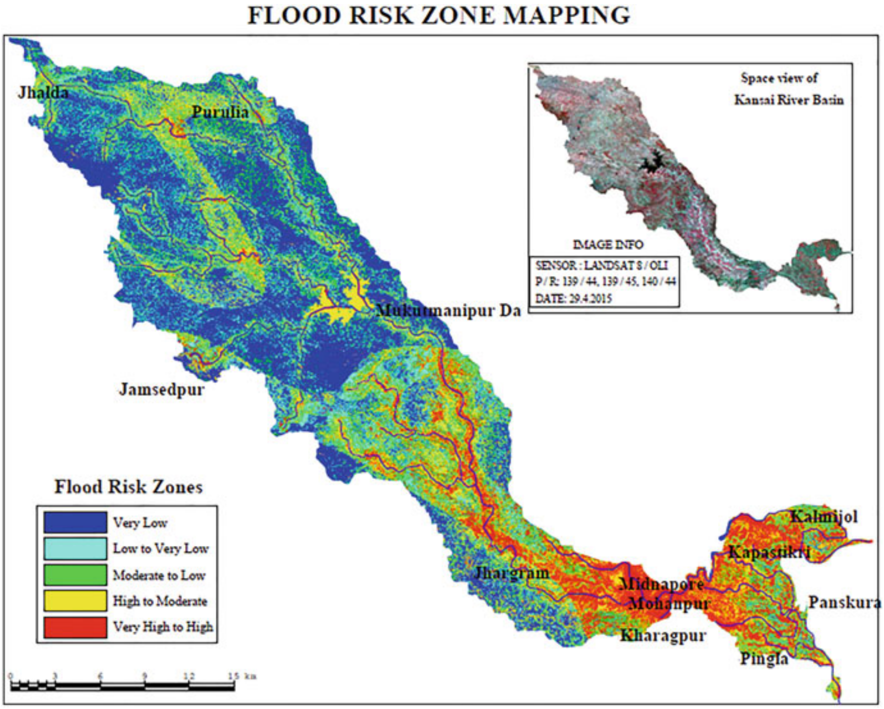


Fig. 6.14 Satellite imageries depicting flood risk zones of Kansai river

et al. 1998). Removing of (**DOC**) concentrations is of primary concern in water resource management. Removing of dissolved organic carbon (**DOC**) from water in a cost-effective manner has become a very challenging task, for river planners and managers can make up a large part of the cost of water treatment from some sources.

6.17.5 Sustainable Water Management

6.17.5.1 Sources and Values of Ground and Surface Water in the Studied River Basin

Out of the total **1900** Km^3 (billion cubic meters or **BCM**) of the estimated potential of all the rivers in India, the ultimate utilizable flow is considered to be only about **700** $\mathbf{Km^3}$. This is because almost about one-third of the potential lies in the North-Eastern region (Cherrapunji in north-east of India, is known as the wettest place in the world) which remains is underutilized.

Out of different rivers in India, the longest is the Ganga followed by the being the Brahamputra, and Ganga, both perennial rivers causing rendering so many benefits

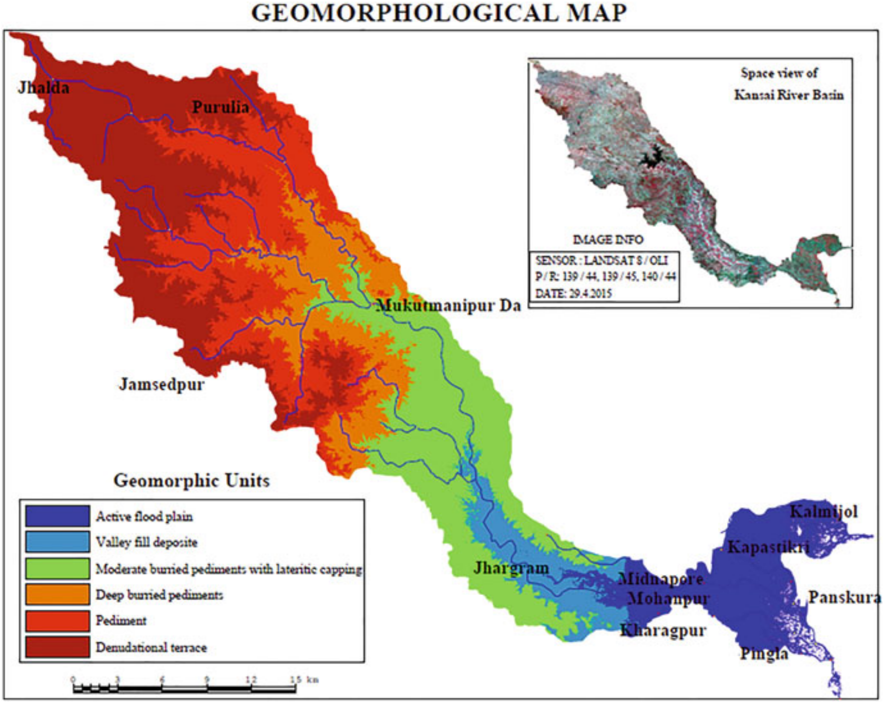


Fig. 6.15 Satellite imageries depicting geomorphological entities of Kansai river

to human societies alongside causing massive destruction in plain areas every year (Environment Report, W. B. P.C.B. 2009). The groundwater resources have multiple values, some of which are extractive, while others are in situ.

In considering trade-offs in resource values, due recognition should are being laid on environmental dependencies, the risk of irreversible impacts and making relevant decisions in tune with the objectives and principles of ecological sustainable development. Rivers represent one of the dynamic ecosystems because of their changing dimensions from the headwater stream to large lowland rivers and from quite summer brooks to flood torrents. It experiences distinct diurnal, monthly, and seasonal variation in respect of physical–chemical– biological–ecological parameters.

As a prime source of freshwater, continuous benefits are being derived from riverine system, viz., water (domestic, industrial, and agricultural), power, navigation, food, and recreation. However, natural hazards alongside anthropological activities mediated different point and non-point sources of pollution pose major threats to the sustainability of riverine resource base. Floods coupled with drought have become the major threats today leading to economic recession, depopulation, and political instability.

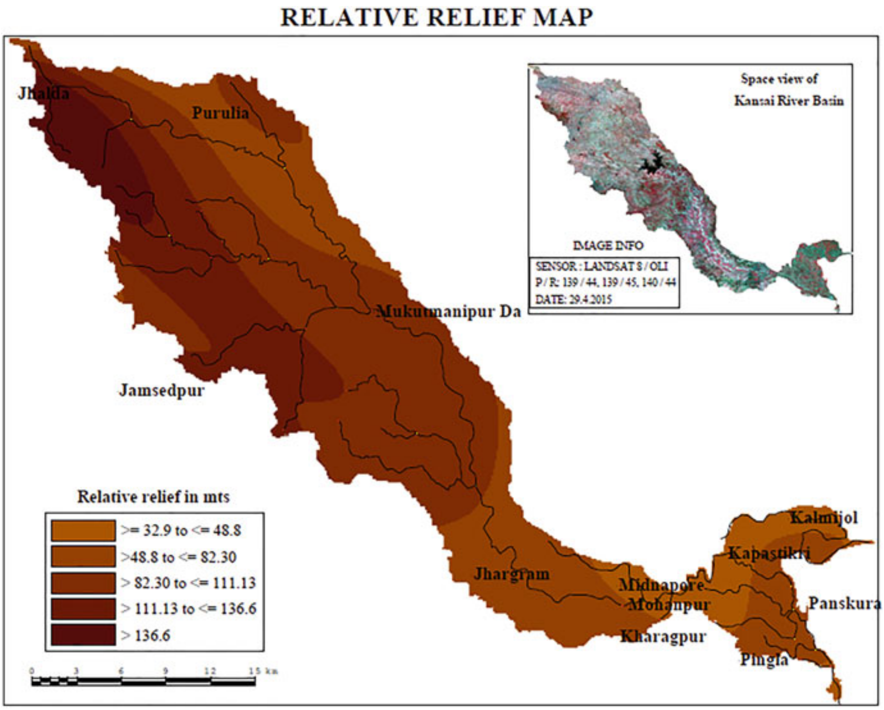


Fig. 6.16 Satellite imageries depicting relief (meters) of Kansai river

In the present time, rapid population growth and increased per capita demand for water especially within the developing countries have resulted acute water scarcity. In the past, the river developments have caused dramatic ecological impacts: a loss of habitat diversity, the reduction of species richness, and decline in productivity. However, the modern approach to river development is founded in the concept of environmental sustainability which incorporates the need to conserve biodiversity.

The biodiversity tends to be a maximum in the river margins which represent the interface between terrestrial and aquatic environments. All surface and groundwater originate from precipitation. Except during rainfall events, most surface water instreams and rivers is furnished by the slow release of groundwater as in the form of "**Base Flow**" which form the primary source of water during periods of low river flow (Cartwright et al. 2005).

Groundwater constitutes the main source of water in most of the river basins including the present studied ones. An increasing demand for the surface and groundwater resources during last couple of centuries has resulted in the depletion of river flow and overdrafting of groundwater.

Such nonjudicious water use has threatened the sustainability of the water resources resulting adverse effects of storage depletion, salinity intrusion, undesirable inter-aquifer flows, subsidence of lands, and groundwater contamination (Hanson et al. 2008) Groundwater is also extracted for human uses in the river

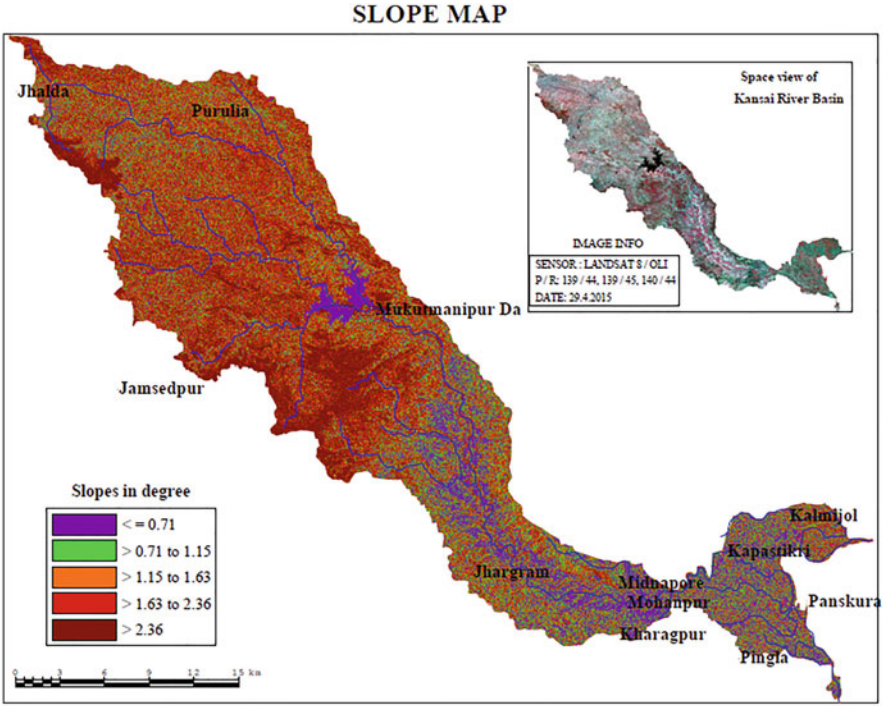


Fig. 6.17 Satellite imageries depicting the sloping pattern (in degree) of Kansai river

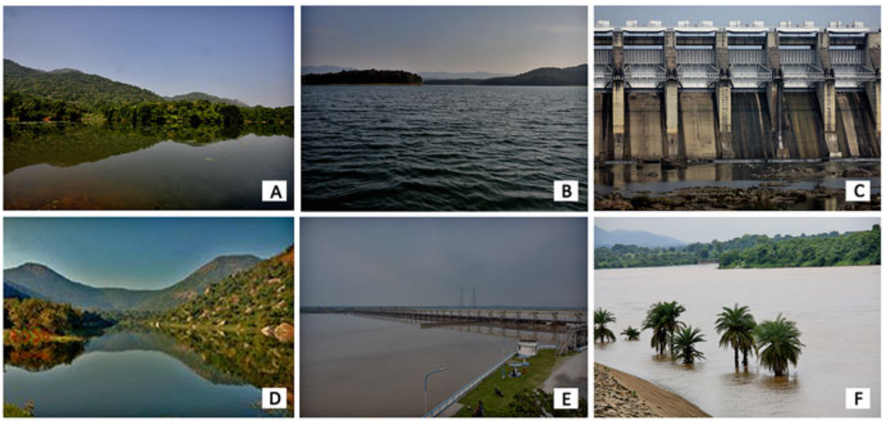
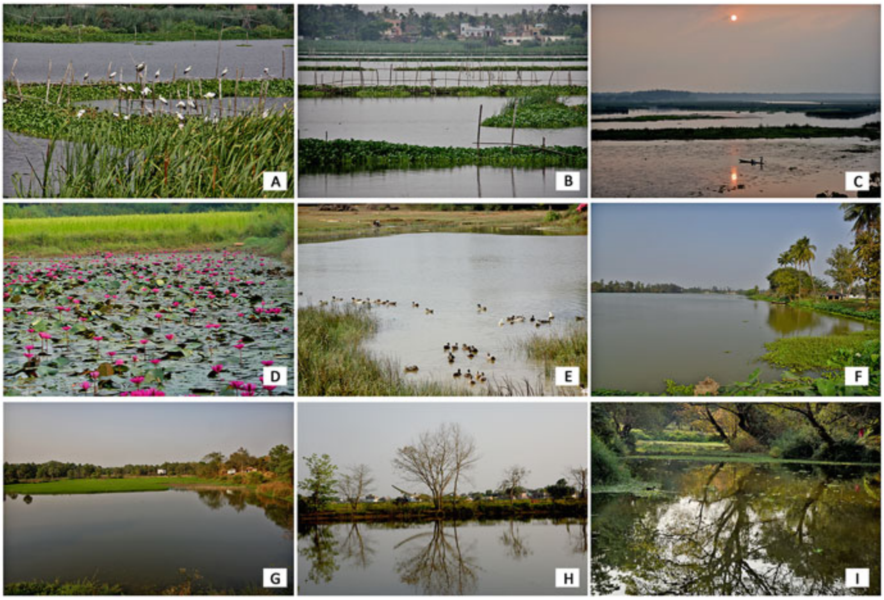
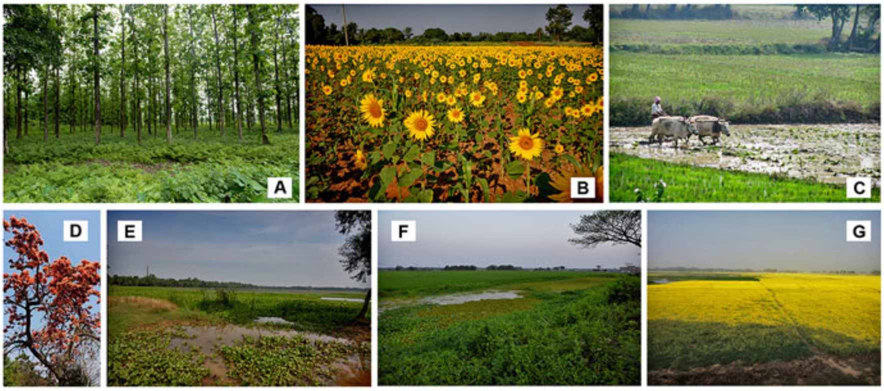


Fig. 6.18 Architectural, environmental, technical excellence of some dams of eastern India. (**A**) Massanjor Dam (Jharkhand); (**B**) Chandil Dam (Jharkhand); (**C**) Sluice gate (Chandil dam); (**D**) massonjor Dam (Jharkhand); (**E**) Testa barriage; (**F**) Galudi Dam



Figs. 6.19 Different floodplains and water bodies (**A–I**) with their biodiversity components and contrasting ecological features along the freshwater riverine networks of south West Bengal, India



Figs. 6.20 Different associated aquatic ecosystems of rivers with their unique structural components. (**A**) Tropical deciduous sal (*Shorea robusta*) dominated forest; (**B**) Cultivation of Sun flower on riverine bank; (**C**) Modern **vs.** Traditional, Agricultural (paddy) activities; (**D**) An indigenous forest plant locally named as (Palash) in the lateritic forest tracts; (**E** and **F**) Eutrophication by the side of agricultural land; (**G**) Mass cultivation of mustard in the river basin with profuse uses of chemical fertilizers, pesticides and considerable lifting of groundwater along with large scale abstraction of surface water to meet huge demands for irrigation

catchment areas and is now being considered as a possible alternative to direct stream extraction.

In the river basins, having strong hydraulic connection between aquifers and river, groundwater extraction can lead to lowering of groundwater levels and a reduction of base flow from groundwater. In extreme cases, base flows can be reduced to an extent that the flow regime of the river catchment is fundamentally changed and rivers can shift from a perennial flow to an ephemeral flow regime (Glennon 2002).

6.17.5.2 Trends of Water Use

The total amount of water abstracted from all sources in the study areas has gradually but steadily increasing over the past **100** years. Total freshwater abstractions for agriculture ranked the first followed abstraction for public water supply. Household use is another component of public water supply. The trend of water usage both from the public water supply and by direct abstraction for industrial and commercial purposes has also been increasing because of lack of awareness for environment.

6.18 Ecosystem Approaches of Management of Rivers Landscape

Over the past few decades, ecosystem approach has become the primary focus on ecological phenomena vis-a-vis eco-management of riverine landscape with all of its entities such as river basins, catchments, watersheds, floodplains, etc. as opposed to engineering, economic, or jurisdictional approach. This novel concept of integrity of different structural components of ecosystems has emerged to understand as a perception of some self-regulatory capacity on the part of an ecosystem and also to recognize the marked responsiveness of many ecological systems to natural and human activities in order to make a pragmatic compromise between detailed reductionist understanding and more comprehensive, holistic meaning.

The goal of ecosystem management could be to maintain or recover the biological integrity of the ecosystem. The concept of the term biological can be defined as "the capability of supporting and maintaining a balanced, integrated, adaptive community of organisms having a species composition, diversity and functional organization comparable to that of natural habitat of the region (Angermeier and Karr 1994).

They state that biotic integrity includes elements e.g. genes, species, populations, assemblages and landscapes) and processes that generate and maintain the elements e.g. selection, evolution, nutrient cycling, disturbance and succession), indicators of biotic integrity vary with levels of biological organization, but they include range size species, age and size structure for populations and resilience to disturbance in assemblages and landscapes.

In large alluvial river–floodplain ecosystems, the prime abiotic factors affecting biotic integrity are water and sediment quality and the temporal patterns of water and sediment flows that shape the river channel and the floodplains themselves. These factors strongly influence habitat structure, the trophic base, and biotic interactions. Ecosystem management includes maintaining water and sediment quality within limits that preserve biological integrity and maintaining or restoring the master processes that enable the river–floodplain ecosystem to maintain, repair, and rejuvenate itself.

Master processes include the abiotic processes of erosion and sedimentation that maintain floodplains and deltas and the biotic processes of colonization and succession that rebuild communities following disturbances. A river basin or watershed or catchment or floodplain represents an integrated system that transforms precipitation, solar radiation, other environmental variables, labor, and capital in the form of green biomass, livestock products, wildlife, recreational and aesthetic satisfactions, and water.

The interactions among the forest management subsystem, the grazing subsystem, the recreation use and development subsystem, and the water management subsystem have been in the continuous process of interaction to producing the vegetation, animal, and soil conditions that govern the yield and quality of its products and services. The only level of ecological theory that can effectively guide management of such complex systems is a theory of ecosystems which explains the interrelationship among the living and nonliving components resulting energy flows and cyclical movement of substances required for the life.

6.19 Conflicts and Solution on the Development of Dams: Both Sides of the Coin in Indian Perspective

6.19.1 India Water Crisis: Groundwater Resource vs Green Revolution

The crisis of groundwater in India is much more serious than it was supposed to be. Around **70%** of the used water out of the total available water in India (both surface and groundwater together) comes from groundwater which is mainly because of rapid pace of urbanization coupled with industrialization. Since the processes of groundwater accumulation and movement are vastly different across hydrogeological settings, the development of any groundwater management also varies significantly from the regions to regions having varied types of agro-climatic conditions. This has necessitated to develop a disaggregated picture of groundwater storage and flow through a careful mapping of the aquifers in the entire country, on the basis of which management strategies and protocols for each hydrogeological setting could be derived. Besides, the emergence of groundwater crisis also coincides with Green Revolution, which is reflected to as the process of increasing agriculture production with the application of modern agro technology such use of hybrid varieties replacing the traditional cultivation with indigenous varieties of crops, profuse application of chemical fertilizers and pesticides, mechanization of the land preparation with modern agriculture appliances, and more dependence on irrigation supports by the abstraction of surface water from the adjoining water bodies mostly rivers and streams and lifting of considerable amount of groundwater leading to the lowering of water table and accumulation of arsenic and fluorides in the groundwater. All these have not only resulted a transition of traditional agriculture to a so-called modern ones with lot of negative ecological implications. Thereby a situation has emerged in the past few decades with the dramatic change and consequences, both positive and negative on the global environment in general and riverine ecosystem in particular. Therefore, the green revolution strategy in India although has made manifold increase in the food production, food security, productivity, expansion of the forest, and farming system setting the stage for dynamism in the agrarian economy, but ruined up so much by the process of bio-magnification of persistent and nondegradable chemical substances, causing eutrophication in most of the water bodies reducing considerably the aquatic productivity, resulting loss of so many indigenous crop species and massive biodiversity loss (earthworms, soil arthropods, algae and nutrient fixing microbes) in the agricultural lands.

6.19.2 Water Resource Management: Narmada Valley Projects (NVP)

In view of ongoing debates on the merits and demerits of the construction of dams across the world, especially in the developing tropical countries dependent mostly on the monsoon fed irrigation, some advocate in favor of the construction of large dams to cater to the need of irrigation and domestic activities during dry season, to promote eco-tourism and fishery, to generate hydroelectric power, etc., whereas the rival lobby strongly argues against such developmental activity mainly on the grounds of ecology and human displacement and designate such development as the development with destruction. After Independence, in the **1950**s, the dominant paradigm for the Government of India on water and its management was based on the construction of large dams across India's major river systems, in order to create irrigation facilities and also to boost up agricultural development utilizing the merits of green revolution and also construction hydro-thermal power projects to boost up generation of power. All those developmental activities were meant for catering to the overall needs of the rapidly growing economy and society. Besides, such developmental activities relating to dams during that period were able to trigger great euphoria with an expectation to unleash and achieve the growth especially in the Indian countryside.

Failure of the of very intention and promise of the Narmada Valley Protects (**NVP**) on Narmada river in India may cited as a vivid example of such discourse which could have the largest river basin scheme in India. The idea of this mega project was conceived to promote better irrigation and modernization of power generation but ultimately succumbed because of the consideration that it would submerge thousands of villages, destroy thousands hectares of forest lands, and displace millions of marginalized peoples.

However, Narmada Projects have had a prolonged conflict-ridden chequired history. Indian authority continued to ignore the importance and need for sustainability and equity even several decades after Independence in respect of water resource development and management. The government of India sanctioned the developmental process for the Narmada Valley Protects [(around **3000** small dams and **30** big dams including the largest one, as Sardar Sarovar Project (SSP)] in the year **1978** which was subsequently received recognition from different international agencies such as World Bank, United Nations Development Program (**UNDP**). Culminations of the ambitions of the planners in the conception and concretization of the Narmada Valley Project (**SSP**) were materialized with construction activities of this project on the western extremity of the river Narmada in the state of Gujarat, India. However, the irony and shortcomings of this very ambitious project (**SSP**) were that benefits were to acquire by the peoples of the state of Gujarat, India, as water mainly flow to that region, whereas most of its displacement and submergence was to take place in the state of Madhya Pradesh, India.

But in the year 1983, the construction activities for this very ambitious developmental project was stopped because of the concerted protests and struggles by the peoples in the name of Narmada Bachao Andolan (**NBA**), under leaderships of several nongovernmental organizations across India and all over the globe. The critique covered financial, economic, social, ecological, and procedural aspects with great rigor and then went on to present a set of possible alternatives to achieve the objectives of the **NVP**. Out of several pertinent question raised by the protesters, a few include lack of adequate rehabilitation of displaced peoples, non-availability of irrigation water to the most of the peoples of the catchment areas, and damage and destruction of forests leading to the loss of many indigenous species. In sequel of such developments, national policy ultimately outlined the great tragedy of displacement, especially of the tribal people and also the violation of the then Forest Rights Act which categorically pointed out historical injustices done to the tribal people of India and recommended for taking up a series of redressal steps for the well-beings and entitlements of the peoples.

Sardar Sarovar Project on the river Narmada that In the face of such national and international protest movements, against the the Narmada Valley Protects, in general and Sardar Sarovar Project (**SSP**) in particular, Government of India was rather compelled to pay proper heed to this burning issue which in other raised the pertinent question questions against the seriousness of the Government's understanding and mindset towards the management water resources in a holistic and integrated manners. In view of the ongoing crisis relating to the scarcity of freshwater, questions were also raised about the strategies of the Government towards ensuring sustainability of groundwater reserves, especially in the face of harmful effects of the Green Revolution that occurred in the middle 1960s. All of these crises and conflicts ultimately prompted the Government to move one step forward for harnessing the bounty of the riverine water resources and below the groundwater tables which got completely unquestioned acceptance (Paranjape and Joy 1995).

In the **1990**s, a proposal was mooted to overcome and resolve the Narmada dispute by restructuring of the **SSP** in order to arrive at a compromise of the fundamental arguments of both sides, those who are in favor of the dam and those, on the other side, staunch resister of the development of the project. The proposal tried to assure the peoples that the water from proposed projects would be made available to the needy areas of the Gujarat causing least submergence, whereas the peoples of the state of Madhya Pradesh, India, would enjoy the lion share of electricity to be generated from the **SSP**. In addition, the proposal puts more stress on creating small local systems of water storage, and large dams would act as supporting structure to disperse and release more water to the smaller reservoirs and thereby to improve water distribution systems and achieve sustainability. However, despite the sincere, committed, and creative efforts on the part of the authority to reach to an amiable and viable solutions to intractable water related problems, the protesters did not pay any heed to accept the proposals (Paranjape and Joy 2006).

References

Agostinho, A.A., F.M. Pelicice, and L.C. Gomes. 2008. Dams and the fish fauna of the Neotropical region: Impacts and management related to diversity and fisheries. *Revista Brasileira de Biologia = Brazilian Journal of Biology* 68 (4 suppl): 1119–1132.

Alexander, W.B., B.A. Southgate, and R. Bassindale. 1935. *Survey of the River Tees II. The estuary – chemical and biological*, Tech. Pap. Wat. Pollut. Res., No. 5 (1935), H.M.S.O., London.

Anderson, J.M., and T.P. Burt. 1978. The role of topography in controlling through flow generation. *Earth Surface Processes and Landforms* 3: 331–344.

Angermeier, P.L., and J.R. Karr. 1994. Biological integrity versus biological diversity as policy directives. *Bioscience* 44 (10): 690–697.

Barbour, M.T., J. Gerritsen, B.D. Snyder, and J.B. Stribling. 1999. *Rapid bio-assessment protocols for use in streams and wadeable rivers: periphyton, benthic macro-invertebrates and fish*. 2nd ed. Washington, DC: EPA 841-B-99–002. Office of Water, US Environmental Protection Agency.

Basson, P.G. 2004. Hydropower dams and fluvial morphological impacts: An African perspective.

Baxter, R.M. 2003. Environmental effects of dams and impoundments. *Annual Review of Ecology and Systematics* 8 (1): 255–283.

Baxter, R.M., and P. Glaude. 1980. Environmental effects of dams and impoundments in Canada: experience and prospects. *Canadian Bulletin of Fisheries and Aquatic Sciences* 205: 1–34.

Bayley, P.B. 1989. Aquatic environments in the Amazon Basin, with an analysis of carbon sources, fish production, and yield. In *Proceedings of the international large rivers symposium*, Canadian special publication in fisheries and aquatic sciences, 106, ed. D.P. Dodge.

Bayley, P.B. 1991. The flood pulse advantage and the restoration of river-flood- plain systems. *Regulated Rivers*: 6, 75–86. 1995. Understanding large river- floodplain ecosystems. Bioscience 45: 153–158.

Bayley, P., and M. Petrere. 1989. Amazon fisheries: Assessment methods, current status and management options. *Canadian Special Publications Fisheries and Aquatic Science* 106: 385–398.

Beechie, T.J., and T.H. Sibley. 1997. Relationships between channel characteristics, woody debris, and fish habitat in Northwestern Washington streams. *Transactions of the American Fisheries Society* 126: 217–229.

Beechie, T., E. Beamer, and L. Wasserman. 1994. Estimating coho salmon rearing habitat and smolt production losses in a large river basin, and implications for habitat restoration. *North American Journal of Fisheries Management* 14: 797–811.

Beechie, T.J., G. Pess, P. Kennard, R.E. Bilby, and S. Bolton. 2000. Modeling recovery rates and pathways for woody debris recruitment in northwestern Washington streams. *North American Journal of Fisheries Management* 20: 436–452.

Beechie, T.J., B.D. Collins, and G.R. Pess. 2001. Holocene and recent geomorphic processes, land use and salmonid habitat in two north Puget Sound river basins. In *Geomorphic processes and riverine habitat. Water science and application*, ed. J.B. Dorava, D.R. Montgomery, F. Fitzpatrick, and B. Palcsak, vol. 4, 37–54. Washington, DC: American Geophysical Union.

Bilby. 1981. Role of organic debris dams in regulating the export of dissolved and particulate matter from a forested watershed. *Ecology* 62: 1234–1243.

Bilby, and J.W. Ward. 1991. Characteristics and function of large woody debris in streams draining old growth, clear-cut, and secondgrowth forests in southwestern Washington. *Canadian Journal of Fisheries and Aquatic Sciences* 48: 2499–2508.

Booth, D.B., and C.R. Jackson. 1997. Urbanization of aquatic systems: degradation thresholds, stormwater detection, and the limits of mitigation. *Journal of the American Water Resources Association* 33: 1077–1090.

Buffington, J.M., and D.R. Montgomery. 1997. 8A systematic analysis of eight decades of incipient motion studies, with special reference to gravel-bedded rivers. *Water Resources Research* 33 (8): 1993–2029.

Calder, I.R. 2007. Forests and water-ensuring forest benefits outweigh water costs. *Forest Ecology and Management* 251: 110–120.

Cartwright, I., A. Maguire, and T. Weaver. 2005. *Groundwater-surface water interaction in the Ovens River, VIC, Australia*. Joint conference of NZ Hydrological Society.

Church, M. 2002. Geomorphic thresholds in riverine landscapes. *Freshwater Biology* 47: 541–557.

Clements, F. 1936. Nature and structure of climax. *Journal of Ecology* 24: 252–284.

Cornell, H.V., and J.H. Lawton. 1992. Species interactions, local and regional processes, and limits to the richness of ecological com- munities: A theoretical perspective. *Journal of Animal Ecology* 61: 1–12.

Colwell, R.K. 1974. Predictability, constancy and contingency of periodic phenomena. *Ecology* 55: 1148–1153.

Cooper, C.M. 1993. Biological effects of agriculturally derived surface water pollutants on aquatic systems – A review. *Journal of Environmental Quality* 22: 402–408.

Costanza, R., R. dArge, R. de Groot, S. Farber, M. Grasso, et al. 1997. The value of the world's ecosystem services and natural capital. *Nature* 387: 253–260. https://doi.org/10.1038/387253A0.

Dahlstrom, N., and C. Nilsson. 2004. Influence of woody debris on channel structure in old growth and managed forest streams in Central Sweden. *Environmental Management* 33: 376–384.

Delong, M.D., and M.A. Brusven. 1998. Macroinvertebrate community structure along the longitudinal gradient of an agriculturally impacted stream. *Environmental Management* 22: 445–457.

Donato, J.Ch., S.R. Duque Escobar, and L.E. Mora-Osejo. 1987. Estructura y dinamica del fitoplancton de la laguna de Fuquene (Cundinamarca, Colombia): Review. *Academia Colombiana* 16: 113–144.

Dotterweich, M. 2008. The history of soil erosion and fluvial deposits in small catchments of central Europe: Deciphering the long-term interaction between humans and the environment – A review. *Geomorphology* 101 (1–2, 192): –208.

Dreibrodt, S., C. Lubos, B. Terhorst, B. Damm, and H.-R. Bork. 2010. Historical soil erosion by water in Germany. Scales and archives, chronology, research perspectives. *Quaternary International* 222 (1–2): 80–95.

Dunne, T., and L.B. Leopold. 1978. *Water in environmental planning*. San Francisco, CA: W.H. Freeman.

Dynesius, M., and C. Nilsson. 1994. Fragmentation and flow regulation of river systems in the northern third of the world. *Science* 266: 753–762.

Enviroment Report. 2009. *West Bengal Pollution Control Board*, 1–352.

Erwin, T.L., and J. Adis. 1982. Amazonian inundation forests, richness and taxa on pulses. In *Biological diversification in the tropics*, ed. G.T. Prance, 358–371. New York: Columbia University Press.

Fausch, K.D., C.E. Torgersen, C.V. Baxter, and H.W. Li. 2002. Landscapes to riverscapes: Bridging the gap between research and conservation of stream fishes. *Bioscience* 52: 483–498.

Feller, I.C., E.M. Dangreemond, D.J. Devlin, C.E. Lovelock, C.E. Proffitt, and W. Rodriguez. 2005. Nutrient enrichment intensifies hurricane impact in scrub mangrove ecosystems in the Indian River Lagoon, Florida, USA. *Ecology* 96 (11): 2960–2973.

Fischenich, J.C. 2006. *Functional objectives for stream restoration. ERDC TN-EMRRP-SR-52*. Vicksburg: U.S. Army Engineer Research and Development Center.

Friedman, J.M., W.R. Osterkamp, M.L. Scott, and G.T. Auble. 1998. Downstream effects of dams on channel geometry and bottomland vegetation: Regional patterns in the Great Plains. *Wetlands* 18 (4): 619–626.

Frissell, C.A., and S.C. Ralph. 1998. Stream and watershed restoration. In *River ecology and management: Lessons from the Pacific coastal ecoregion*, ed. R.J. Naiman and R.E. Bilby. New York: Springer.

Frissell, C.A., W.J. Liss, C.E. Warren, and M.D. Hurley. 1986. A hierarchical framework for stream habitat classification—Viewing streams in a watershed context. *Environmental Management* 10: 199–214.

Giosan, L., P.D. Clift, M.G. Macklin, D.Q. Fullerd, S. Constantinescu, Duran, T. Stevens, G.A.T. Duller, A.R. Tabrez, K. Gangal, R. Adhikari, A. Alizai, F. Filip, S. Van Laningham, and J.P.M. Syvitski. 2012. Fluvial landscapes of the Harappan civilization. *Proceedings of the National Academy of Science* 109 (26). https://doi.org/10.1073/pnas.1112743109.

Glennon, R.J. 2002. *Water follies: Groundwater pumping and the fate of America's fresh waters*. Washington, DC: Island Press.

Goulding, M. 1980. *The fishes and the forest: Explorations in Amazonian natural history*, 280 p. Los Angeles, CA: University of California Press.

Greenwood, K.L., D.A. MacLeod, and K.J. Hutchinson. 1997. Long-Term stocking rate effects on soil physical properties. *Australian Journal of Experimental Agriculture* 37: 413–419.

Grill, G., B. Lehner, M. Thieme, B. Geenen, D. Tickner, F. Antonelli, S. Babu, P. Borrelli, L. Cheng, H. Crochetiere, H. Ehalt Macedo, R. Filgueiras, M. Goichot, J. Higgins, Z. Hogan, B. Lip, M.E. McClain, J. Meng, M. Mulligan, C. Nilsson, J.D. Olden, J.J. Opperman, P. Petry, C. Reidy Lierman, L. Saenz, S. Salinas-Rodriguez, P. Schelle, R.J.P. Schmitt, J. Snider, F. Tan, K. Tockner, P.H. Valdujo, A. van Soesbergen, and C. Zarfl. 2019. Mapping the World's free flowing rivers. *Nature* 569: 215–221.

Hanson, A., L. Swanson, D. Ewing, G. Grabas, S. Meyer, L. Ross, M. Watmough, and J. Kirkby. 2008. *Wetland ecological functions assessment: An overview of approaches (Atlantic region): Technical report series number 497*, Canadian Wildlife Service Technical Report Series, 1–59.

Hart, B.T., ed. 1986. *Water quality management: The role of particulate matter in the transport and fate of pollutants*. Melbourne: Water Studies Centre, Chisholm Institute of Technology and Australian Society for Limnology.

Holman, I.P., J.M. Hollis, M.E. Bramley, and T.R.E. Thompson. 2003. The contribution of soil structure degradation to catchment flooding: A preliminary investigation of the 2000 floods in England and Wales. *Hydrology and Earth System Sciences* 7: 507–526.

Howden, N.J.K., and T.P. Burt. 2008. Statistical analysis of nitrate concentrations from the Rivers Frome and Piddle (Dorset, UK) for the period 1965–2007. *Ecohydrology* 1 (2): 55–65.

Howden, N.J.K., and L.K. Deeks. 2007. Soil *examination, rainfall simulation and soil runoff and infiltration experiments following a flood event in the Boscastle Area*, July, 2007. Report to the Environment Agency. Cranfield University, UK.

Hudon, C., and R. Carignan. 2008. Cumulative impacts of hydrology and human activities on water quality in the St. Lawrence River (Lake Saint-Pierre, Quebec, Canada). *Canadian Journal of Fisheries and Aquatic Sciences* 65: 1165–1180.

Hynes, H.B.N. 1975. Edgardo Baldi memorial lecture. The stream and its valley. *Verhandlungen der Inter- 206 R. H. Norris and M. C. Thoms ã 1999 nationalen Vereinigung fuÈ r Theoretische und Angewandte Limnologie* 19: 1–15.

Jansson, R., C. Nilsson, M. Dynesius, and A. Elisabet. 2000. Effects of river regulation on river-margin vegetation: A comparison of eight boreal rivers. *Ecological Applications* 10 (1): 203–224.

Jansson, À., C. Folke, J. Rockstrom, and L. Gordon. 1999. Linking freshwater flows and ecosystem services appropriated by people: The case of the Baltic Sea drainage basin. *Ecosystems* 2: 351–366.

Jansson, M., L. Persson, A.M. de Roos, R.I. Jones, and L.J. Tranvik. 2007. Terrestrial carbon and intraspecific size-variation shape lake ecosystems. *Trends in Ecology & Evolution* 22: 316–322.

Jobin, W.R. 1999. *Dams and disease: Ecological design and health impacts of large dams, canals, and irrigation systems*. London/New York: E & FN Spon, Routledge.

Johnson, L.B., C. Richards, G.E. Host, and J.W. Arthur. 1997. Landscape influences on water chemistry in Midwestern stream ecosystems. *Freshwater Biology* 37: 193–208.

———., ed. 2011. *Handbook of ecological models used in ecosystem and environmental management*. Boca Raton, FL: CRC Press, 620pp.

Jørgensen, S.E. 2002. *Integration of ecosystem theories: A pattern*. 3rd rev ed.

———. 2012a. *Fundamentals of systems ecology*. Boca Raton, FL: CRC Press. 320 pp.

———. 2012b. *Fundamentals of systems ecology*. Boca Raton: Taylor & Francis Group, 320pp.

Jørgensen, S.E., and B. Fath. 2011. *Fundamentals of ecological modelling*, Application in environmental management and research. 4th ed. Amsterdam: Elsevier, 390pp.

Junk, W.J. 1973. Investigations on the ecology and production biology of the floating meadows (Paspalo-Echinochloetum) on the Middle Amazon, Part 2: the aquatic fauna in the root zone of floating vegetation. *Amazoniana* IV: 9–102.

Junk, W.J., and R.L. Welcomme. 1990. Floodplains. In *Wetlands and shallow continental water bodies*, ed. B.C. Patten et al., 491–524. The Hague: SPB Academic Publishers.

Junk, W.J., P.B. Bayley, and R.E. Sparks. 1989a. The flood pulse concept in river-floodplain systems. *Canadian Special Publication of Fisheries and Aquatic Sciences* 106: 110–127.

Junk, W.J., P.B. Bayley, and R. E. Sparks. 1989b. *The flood pulse concept in river-floodplain systems*. In Proceedings of the international large river symposium, Can. Spec. Publ. Fish. Aquat. Sci., ed. DP Dodge, 106: 110–27.

Kareiva, P., and U. Wennergren. 1995. Connecting landscape patterns to ecosystem and population processes. *Nature* 373: 299–302.

Kareiva, P., S. Watts, R. McDonald, and T. Boucher. 2007. Domesticated nature: Shaping landscapes and ecosystems for human welfare. *Science* 316: 1866–1869.

Kidd, K.A., P.J. Blanchfield, K.H. Mills, V.P. Palace, R.E. Evans, J.M. Lazorchak, and R.W. Flick. 2007. Collapse of a fish population after exposure to a synthetic estrogen. *Proceedings of the National Academy of Sciences* 104: 8897–8901.

Kiffney, P.M., and J.S. Richardson. 2010. Organic matter inputs into headwater streams of southwestern British Columbia as a function of riparian reseves and time since harvesting. *Forest Ecology and Management* 260: 1931–1942.

Kiffney, P.M., J.S. Richardson, and J.P. Bull. 2003. Responses of periphyton and insects to experimental manipulation of riparian buffer width along forest streams. *Journal of Applied Ecology* 40: 1060–1076.

———. 2004. Establishing light as a causal mechanism structuring stream communities in response to experimental manipulation of riparian buffer width. *Journal of the North American Benthological Society* 23: 542–555.

Kimmel, B.L., and A.W. Groeger. 1984. Factors controlling primary production in lakes and reservoirs; A perspective. In *Lake and reservoir management*, 277–281. U.S. EPA-440/5-84-001.

Klinkenberg, E., W. Takken, F. Huibers, and Y.T. Toure. 2003. The phenology of malaria mosquitoes in irrigated rice fields. *MaliActa Tropica* 857182.

Kolpin, D.W., E.T. Furlong, M.T. Meyer, E.M. Thurman, S.D. Zaugg, et al. 2002. Pharmaceuticals, hormones, and other organic wastewater con- taminants in US streams, 1999-2000: A national reconnaissance. *Environmental Science & Technology* 36: 1202–1211.

Kondolf, G.M. 1997. Hungry water: Effects of dams and gravel mining on river channels. *Environmental Management* 21: 533–551.

Kondolf, G.M., Y. Gao, G.W. Annandale, G.L. Morris, E. Jiang, J. Zhang, Y. Cao, P. Carling, K. Fu, Q. Guo, R. Hotchkiss, C. Peteuil, T. Sumi, H.-W. Wang, Z. Wang, Z. Wei, B. Wu, C. Wu, and C.T. Yang. 2014. Sustainable sediment management in reservoirs and regulated rivers: Experiences from five continents. *Earths Future* 2: 256–280.

Lang, H. 1986. Forecasting melt water runoff from snow-covered areas and from glacier basins. In *River flow modelling and forecasting*, ed. D.A. Kraijenhoff and J.R. Moll, 99–127. Dordrecht: D. Reidel Publishing Company.

Lang, Andreas, Hans-Rudolf Bork, Rudiger Mackel, and Nicholas Preston. 2003. Changes in sediment flux and storage within a fluvial system: Some examples from the Rhine catchment. *Hydrological Processes* 17 (16): 3321–3334.

Lehner, B., C.R. Liermann, C. Revenga, C. Vorosmarty, B. Fekete, P. Crouzet, P. Doll, M. Endejan, K. Frenken, J. Magome, C. Nilsson, J.C. Robertson, R. Rodel, N. Sindorf, and D. Wisser. 2011. High-resolution mapping of the world's reservoirs and dams for sustainable river-flow management. *Frontiers in Ecology and the Environment* 9: 494–502.

Lehnner, B., and P. Doll. 2004. Development and validation of a global database of lakes, reservoirs and wetlands. *Journal of Hydrology* 296: 1–22.

Leith, H., and R.H. Whittaker. 1975. *Primary productivity of the biosphere*. New York: Springer.

Lenat, D.R., and J.K. Crawford. 1994. Effects of landuse on water quality and aquatic biota of three North Carolina Piedmont streams. *Hydrobiologia* 294: 185–199.

Lewis, W.M., Jr., S.K. Hamilton, M.A. Lasi, M. Rodrı'guez, and J.F. Saunders III. 2000. Ecological determinism on the Orinoco floodplain. *Bioscience* 50: 681–692.

Lewis, W.M., Jr., W.M. Lewis Jr., S.K. Hamilton, M.A. Rodriquez, J.F. Saunders III, and D.H. Lasi. 2001. Foodweb analysis of the Orinoco floodplain based on production estimates and stable isotope data. *Journal of the North American Benthological Society* 20: 241–254.

Likens, G.E., ed. 2010. *River ecosystem ecology. A global perspective*, 424 p. London: Academic Press.

Likens, Gene E., et al. 1970. Effects of forest cutting and herbicide treatment on nutrient budgets in the Hubbard Brook watershed-ecosystem. *Ecological Monographs* 40: 23–47.

Likens, G.E., F.T. Mackenzie, J.E. Richey, J.R. Sedell, and K.K. Turekian. 1981. *Flux of organic carbon by rivers to the sea*. Conf. 8009140. DOE, Office Energy Res., Washington, DC.

Limburg, K.E., and R.E. Schmidt. 1990. Patterns of fish spawning in Hudson River tributaries: Response to an urban gradient ? *Ecology* 71 (4): 1238.

Lipp, Erin K. 2002. Molecular assays for targeting human and bovine enteric viruses in coastal waters and their application for library -independent source tracking. *Applied and Environmental Microbiology*.

Lipp, E.K., R. Kurz, R. Vincent, C. Rodriguez-Palacios, S.R. Farrah, and J.B. Rose. 2001. The effects of seasonal variability and weather on microbial fecal pollution and enteric pathogens in a subtropical estuary. *Estuaries* 24: 266–276.

Lowrance, R., R. Todd, J. Fail Jr., O. Hendrickson Jr., R. Leonard, and L. Asmussen. 1984. Riparian forests as nutrient filters in agricultural watersheds. *Bioscience* 34 (6): 374–377.

Marques, M.J., E. Martinez-Conde, and J.V. Rovira. 2003. Effects of zinc and lead mining on the benthic macroinvertebrates of a fluvial ecosystem. *Water, Air and Soil Pollution* 148 (4): 363–368.

Mayer, G.A., J.L. Pierce, S.H. Wood, and A.J.T. Jull. 2001. Fire, storms, and errosional events in the Idaho batholith. *Hydrological Processes* 15: 3025–3038.

Megahan, W.F., J.P. Potyondy, and K.A. Seyedhagheri. 1992. Best management practices and cumulative effects from sedimentation in the South Fork Salmon River: An Idaho case study. In *Watershed management*, ed. R.J. Naiman, 401–414. New York: Springer.

Minshall, G., K.W. Cummns, R.C. Petersen, C. Cushing, D.A. Brus, J.R. Sedell, et al. 1985. Developments in stream ecosystem theory. *Canadian Journral of Fisheries and Aquatic Science* 42: 1045–1055.

Mitsch, W.J., and J.G. Gosselink. 1986. *Wetlands*. Van Nostrand Reinhold: New York.

———. 1993. *Wetlands*. 2nd ed. New York: Van Nostrand Reinhold.

Montgomery, J.C., S. Coombs, and M. Halstead. 1995. Biology of the mechanosensory lateral line in fishes. *Reviews in Fish Biology and Fisheries* 5: 399–416.

Morley, S.A., and J.R. Karr. 2002. Assessing and restoring the health of urban streams in the Puget Sound basin. *Conservation Biology* 16: 1498–1509.

Moyle, P.B., and B. Herbold. 1987. Life- history patterns and community structure in stream fishes of Western North America: Comparisons with Eastern North America and Europe. In *Community and evolutionary ecology of North American stream fishes*, ed. W.J. Matthews and D.-C. Heins, 25–32. Norman, OK: University of Oklahoma Press.

Nanson, G.C., and J.C. Croke. 1992. A genetic classification of floodplains. *Geomorphology* 4 (6): 459–486.

Neal, C. 1997. A view of water quqlity from Plynlimnon watershed. *Hydrology and Earth System Sciences* 1: 743–753.

Negishi, J.N., Y. Kayaba, and S. Sagawa. 2008. Ecological consequences of changing riverscape: terrestrialization of floodplain and freshwater mussels (in Japanese). *China Civil Engineering Journal* 50: 38–41.

Newcombe, C.P., and J.O.T. Jensen. 1996. Channel suspended sediment and fisheries: A synthesis for quantitative assessment of risk and impact. *North American Journal of Fisheries Management* 16 (4): 693–727.

Nguyen, M.L., G.W. Sheath, C.M. Smith, and A.D. Cooper. 1998. Impact of cattle treading on hill land.2. Soil physical properties and contaminant runoff. *New Zealand Journal of Agricultural Research* 41: 279–290.

Nilsson, M.C., and D.A. Wardle. 2005. Understory vegetation as a forest ecosystem driver: Evidence from the northern Swedish boreal forest. *Frontiers in Ecology and the Environment* 3: 421–428.

Nilsson, C., R. Jannson, and U. Zinko. 1997. Long-term responses of river-margin vegetation to water-level regulation. *Science* 276: 798–800.

Nilsson, C., C.A. Reidy, M. Dynesius, and C. Revenga. 2005. Fragmentation and flow regulation of the world's large river systems. *Science* 308: 405–408.

Nitschke, C.R. 2005. Does forest harvesting emulate fire disturbance ? A comparison of effects on selected attributes in coniferous-dominated head water systems. *Forest Ecology and Management* 214: 305.

O'Connell, E., J.O. Ewen, G. Donnel, and P. Quinn. 2007. Is there a link between agricultural land-use management and flooding? *Hydrology and Earth System Sciences* 11: 96–107.

Ofenböck, T., O. Moog, J. Gerritsen, and M.T. Barbour. 2004. A stressor specific multimetric approach for monitoring running waters in Austria using benthic macro-invertebrates. *Hydrobiologia* 516: 251–268.

Osborne, L.L., and D.A. Kovacic. 1993. Riparian vegetated buffer strips in water-quality restoration and stream management. *Freshwater Biology* 29: 243–258.

Ourso, R.T., and S.A. Frenzel. 2003. Identification of linear and threshold response in streams along a gradient of urbanization in Anchorage, Alaska. *Hydrobiologia* 501: 117–131.

Palmer, M.A., R.F. Ambrose, and N.L. Poff. 1997. Ecological theory and community restoration ecology. *Restoration Ecology* 5: 291–300.

Paranjape, S., and K.J. Joy. 1995. *Sustainable technology: Making the Sardar Sarovar project viable*. Ahmedabad: Centre for Environment Education, Nehru Foundation for Development.

———. 2006. Alternative restructuring of the Sardar Sarovar: Breaking the deadlock. *Economic and Political Weekly* 41 (7): 601–602.

Pelicice, F.M., and A.A. Agostinho. 2008. Fish passage facilities as ecological traps in large Neotropical rivers. *Conservation Biology* 22: 180–188.

Pelicice, F.M., J.R.S. Vitule, D.P. Lima Junior, M.L. Orsi, and A.A. Agostinho. 2014. A serious new threat to Brazilian freshwater ecosystems: the naturalization of nonnative fish by decree. *Conservation Letters* 7: 55–60.

Perez-Arlucea, M.M., and N.D. Smith. 1999. Depositional patterns following the 1870s avulsion of the Saskatchewan River (Cumberland Marshes, Saskatchewan, Canada). *Journal of Sedimentary Research* 69 (1): 62–73.

Penland, S., and R. Boyd. 1985. Mississippi Delta barrier shoreline development. In *Transgressive depositional environments of the Mississippi river delta plain: A guide to the Barrier islands, beaches, and Shoals in Louisiana*, ed. S. Penland and R. Boyd, 53–121. Baton Rouge, LA: Louisiana Geological Survey.

Petts, G.E. 1985. *Impounded rivers – Perspectives for ecological management*. Chichester: Wiley.

Pianka, E.R. 1970. On r- and K-selection. *The American Naturalist* 104: 592–597.

Pickett, S.T.A., and P.S. White, eds. 1985. *The ecology of natural disturbance and patch dynamics*, 472. New York: Academic Press.

Piedade, M.T.F., W.J. Junk, and S.P. Long. 1991. The productivity of the C4 grass *Echinochloa polystachya* on the Amazon floodplain. *Ecology* 72: 1456–1463.

Pinay, G., and H. Decamps. 1988. The role of riparian woods in regulating nitrogen fluxes between the alluvial aquifer and surface water: A conceptual model. *Regulated Rivers: Environment, Ecology, and Management* 2: 507–516.

Poff, N.L. 1997. Landscape filters and species traits: Toward mechanistic understanding and prediction in stream ecology. *Journal of the North American Benthological Society* 16: 391–409.

Poff, N.L., and D.D. Hart. 2002. How dams vary and why it matters for the emerging science of dam removal. *Bioscience* 52: 659–668.

Poff, N.L., J.D. Allan, M.B. Bain, J.R. Karr, K.L. Prestegaard, B.D. Richter, R.E. Sparks, and J.C. Stromberg. 1997. The natural flow regime: A paradigm for river conservation and restoration. *Bioscience* 47: 769–784.

Poff, N.L., J.D. Olden, N.K.M. Vieira, D.S. Finn, M.P. Simmons, and B.C. Kondratieff. 2006. Functional trait niches of north American lotic insects: Traits-based ecological applications in light of phylogenetic relationships. *Journal of the North American Benthological Society* 25: 730–755.

Poff, N.L., J.D. Olden, D.M. Merritt, and D.M. Pepin. 2007. Homogenization of regional river dynamics by dams and global biodiversity implications. *Proceedings of the National Academy of Sciences* 104: 5732–5737. https://doi.org/10.1073/pnas.0609812104.

Pont, D., B. Hugueny, and C. Rogers. 2007. Development of a fish-based index for the assessment of river health in Europe: The European fish index. *Fisheries Management and Ecology* 14: 427–439.

Quinn, G.P., T.J. Hillman, and R. Cook. 2000. The response of macro invertebrates to inundation in floodplain wetlands: A possible effect of river regulation. *Regulated Rivers: Research & Management* 16: 469–477.

Rangachari, R., N. Sengupta, R.R. Iyer, P. Banerji, and S. Singh. 2000. *Large dams: India's experience*. WCD case study. www.dams.org.

Rauzi, F., and F.M. Smith. 1972. Infiltration rates: Three soils with three grazing levels in northeastern Colorado. *Journal of Range Management* 26: 126–129.

Raymond, P.A., Oh. Neung-Hwan, R.E. Turner, and W. Broussard. 2008. Anthropogenically enhanced fluxes of water and carbon from the Mississippi river. *Nature Publishing Group* 451: 449–452.

Reid, M.A., and R.W. Ogden. 2006. Trend, variability or extreme event? The importance of long-term perspectives in river ecology. *River Research and Applications* 22: 167–177.

———. 2009. Factors affecting diatom distribution in floodplain lakes of the Southeast Murray Basin, Australia and implications for palaeolimnological studies. *Journal of Paleolimnology* 41: 453–470.

Reid, M.A., C.D. Sayer, A.P. Kershaw, and H. Heijnis. 2007. Palaeolimnological evidence for submerged plant loss in a floodplain lake associated with accelerated catchment soil erosion (Murray River, Australia). *Journal of Paleolimnology* 38: 191–208.

Richards, C., and G.E. Host. 1994. Examining land use influences on stream habitats and macroinvertebrates: A GIS approach. *Water Resources Bulletin* 30: 729–738.

Richards, C., L.B. Johnson, and G.E. Host. 1996a. Landscape scale influences on stream habitats and biota. *Canadian Journal of Fisheries and Aquatic Sciences* 53: 295–311.

Richards, K.S., F.M.R. Hughes, A. El-Hames, T. Harris, G. Pautou, J.-L. Peiry, and J. Girel. 1996b. Integrated field, laboratory and numerical investigations of hydrological influences on the establishment of riparian tree species. In *Floodplain processes*, ed. M.G. Anderson and D.E. Walling, 611–635. Chichester: Wiley.

Richter, B.D., and G.A. Thomas. 2007. Restoring environmental flows by modifying dam operations. *Ecology and Society* 12 (1): 12. [online] URL: http://ecologyandsociety.org/vol12/iss1/art12. Accessed 24 Oct 2007.

Richter, B.D., J.V. Baumgartner, J. Powell, and D.P. Braun. 1996. A method for assessing hydrologic alteration within ecosystems. *Conservation Biology* 10 (4): 1163–1174.

Robinson, M., and A. Dupyrat. 2005. Effects of commercial timber harvesting on streamflow regimes in the Plynlimon catchments, mid-Wales. *Hydrological Processes* 19: 1213–1226.

Robinson, C.T., K. Tockner, and J.V. Ward. 2002. The fauna of dynamic riverine landscapes. *Freshwater Biology* 47: 661–677.

Rosenberg, M.J., D.C. Adams, and J. Gurevitch. 2000. *Metawin 2.0 user's manual: Statistical software for meta- analysis*. Sunderland, MA: Sinauer Associates.

Roth, N.E., J.D. Allan, and D.L. Erickson. 1996. Landscape influences on stream biotic integrity assessed at multiple spatial scales. *Landscape Ecology* 11: 141–156.

Roy, K., D. Jablonski, and J. Valentine. 2004. Beyond species richness: Biogeographic patterns and biodiversity dynamics using other metrics of diversity. In *Frontiers of biogeography*, ed. M.V. Lomolino and L.R. Heaney, 151–170. Sunderland, MA: Sinaue.

Rueda, F., E. Moreno-Ostos, and J. Armengo. 2006. The residence time of river water in reservoirs. *Ecological Modelling* 191: 260–274.

Schlosser, I.J. 1987. A conceptual framework for fish communities in small warmwater streams. In *Communty and evolutionary ecology of North American stream fishes*, ed. W.J. Matthews and D.C. Heins, 17–24. Norman: University of Oklahoma Press.

Sedell, R., and R.L. Vannote. 1985. Developments in stream ecosystem theory. *Canadian Journal of Fisheries and Aquatic Sciences* 42: 1045–1055.

———. 1991. Stream fish ecology: A landscape perspective. *Bioscience* 41: 704–712.

Shafroth, P.B., J.C. Stromberg, and D.T. Patten. 2002. Riparian vegetation response to altered disturbance and stress regimes. *Ecological Applications* 12: 107–123.

Skinner, J.A., K.A. Lewis, K.S. Bardon, P. Tucker, J.A. Catt, and B.J. Chambers. 1997. An overview of the environmental impact of agriculture in the U.K. *Journal of the Environmental Management* 50: 111–128.

Snelder, T.H., and B.J.F. Biggs. 2002. Multi-scale river environment classification for water resource management. *American Water Resources Association* 38: 1225–1239.

Sparks, R.E. 1995. Need for ecosystem management of large rivers and their flood- plains. *Bioscience* 45: 168–182.

Sparks, R.E., P.B. Bayley, S.L. Kohler, and L.L. Osborne. 1990. Disturbance and recovery of large floodplain rivers. *Environmental Management* 14: 699–709.

Sparks, R.E., J.C. Nelson, and Y. Yin. 1998. Naturalization of the flood regime in regulated rivers. *Bioscience* 48: 706–720.

Stanley, E.H., S.G. Fisher, and andGrimm, N.B. 1997. Ecosystem expansion and contraction in streams. *Bioscience* 47: 427–435.

Stanley, S. 1990. Delayed recovery and the spacing of major extinctions: Paleobiology. *Paleobiology* 16: 401–414.

Stephens, W., T.M. Hess, and J. Knox. 2001. *Review of the effects of energy crops on hydrology*. Report to Ministry of agriculture, fisheries and food, project NF0416. Cranfield University, U.K.

Strand, M., and R. Merritt. 1999a. Impacts of livestock grazing activities on stream insect communities and the riverine environment. *American Entomologist* 45 (1): 13–29.

Strand, M., and R.W. Merritt. 1999b. Impact of livestock grazing activities on stream insect communities and the riverine environment. *American Entomologist* 45: 13–27.

Straskraba, M. 1979. Natural control mechanisms in models of aquatic ecosystems. *Ecological Modelling* 6: 305–322.

———. 1993. Ecotechnology as a new means for environmental management. *Ecological Engineering* 2 (4): 311–331.

Strayer, D.L., H.M. Malcolm, R.E. Bell, S.M. Carbotte, and F.O. Nitsche. 2000. Using geophysical information to define benthic habitats in a large river. *Freshwater Biology* 51: 25–48.

Streeter, W.H., and E.B. Phelps. 1925. *A study of the pollution and natural purification of the Ohio River*, Public Health Bulletin. 146. Washington, DC: U.S. Public Health Service.

Sweeney, B.W., T.L. Bott, J.K. Jackson, L.A. Kaplan, J.D. Newbold, L.J. Standley, W.C. Hession, and R.J. Horwitz. 2004. Riparian deforestation, stream narrowing, and loss of stream ecosystem services. *Proceedings of the National Academy of Sciences of the United States of America* 101: 14132–14137.

Temme, C., P. Blanchard, A. Steffen, S.T. Beauchamp, L. Poissant, R.J. Tordon, and B. Weins. 2007. Trend, seasonal and mulivariate analysis study of total gaseous mercury data from the Canadian Atmospheric Mercury Measurement Network I CAM NET. *Atmospheric Environment* 41 (26): 135–153.

Tong, S.T.Y., and W. Chen. 2002. Modeling the relationship between land use and surface water quality. *Journal of Environmental Management* 66 (4): 377–393.

Townsend, C.R. 1989. The patch dynamics concept of stream community ecology. *Journal of the North American Benthological Society* 8: 36–50.

Townsend, C.R. 1996. Concepts in river ecology: Pattern and process in the catchment hierarchy. *Archiv fur Hydrobiologie*, Supp 113, Large Rivers 10: 3–21.

Townsend, C.R., M.R. Scarsbrook, and Dole'dec S. 1997. The intermediate disturbance hypothesis, refugia, and biodiversity in streams. *Limnology and Oceanography* 42: 938–949.

Trimble, S.W., and A.C. Mendel. 1995. The cow as a geomorphic agent, A critical review. *Geomorphology* 13: 233–253.

Usseglio-Polatera, Philippe, and Jean-Nicholas Beisel. 2002. Longitudinal changes in macroinvertebrate assemblages in the Meuse River: Anthropogenic effects versus natural change. *River research and Applications* 18 (2): 197–211.

Vannote, R.L., et al. 1980. The river continuum concept. *Canadian Journal of Fisheries and Aquatic Sciences* 37: 130–137.

Volk, M., J. Hirschfeld, A. Dehnhardt, G. Schmidt, C. Bohn, S. Liersch, and P.W. Gassman. 2008. Integrated ecological-economic modelling of water pollution abatement management options in the upper Ems river basins. *Ecological Economics* 66: 66–76.

Volk, M., S. Lautenbach, H. van Delden, and L.T.H. Newham. 2010. How can we make progress with decision support systems in landscape and river basin management ? Lessons learned from a comparative analysis of four different decision support systems.Environmental. *Management* 46 (6): 834–849.

Vorosmarty, C.J., M.P. Gildea, B. Moore, J. Peterson, B. Bergquist, and J.M. Melillo. 1986. A global model of nutrient cycling, II. Aquatic processing, retention and distribution of nutrients in large drainage basins. In *Watershed research perspectives*, ed. D. Correll, 32–56. Washington, DC: Smithsonian Institution Press.

Vorosmarty, C.J., B. Moore, A.L. Grace, and M.P. Gildea. 1989. Continental scale models of water balance and fluvial transport: An application to South America. *Global Biogeochemical Cycles* 3 (3): 241–265.

Vörösmarty, C.J., P. Green, J. Salisbury, and R.B. Lammers. 2000. Global water resources: Vulnerability from climate change and population growth. *Science* 289: 284–288.

Vyas, V., D. Damde, and V. Parashar. 2010. Fish biodiversity of Betwa river in Madhya Pradesh, India with special reference to Sacred Ghat. *International Journal of Biodiversity Conservation* 4 (2): 71–77.

Walter, R.C., and D. Merritts. 2008. Natural streams and the legacy of water-powered mills. *Science* 319 (5861): 299–304. White (1969).

Walsh, P.D., K.A. Abernethy, M. Bermejo, R. Beyers, P. De Wachter, M.E. Akou, B. Huljbregis, D.I. Mambounga, A.K. Toham, A.M. Kilbourn, S.A. Lahm, S. Latour, C. Walter, and J.F. Kiutchell. 2001. Cultivation/depensation effects on juvenile survival and recruitment: Implications for the theory of fishing. *Canadian Journal of Fisheries and Aquatic Sciences* 58: 39–50.

Wang, L., J. Lyons, P. Kanehl, and R. Gatti. 1997. Influences of watershed land use on habitat quality and biotic integrity in Wisconsin streams. *Fisheries* 22: 6–12.

Wang, L., J. Lyons, and P. Kanehl. 2001. Impacts of urbanization on stream habitat and fish across multiple spatial scales. *Environmental Management* 28: 255–266.

Ward, J.V. 1998. Riverine landscapes: Biodiversity patterns, disturbance regimes, and aquatic conservation. *Biological Conservation* 83: 269–278.

Ward, J.V., G. Bretschko, M. Brunke, D. Danielopol, J. Gibert, T. Gonser, and A.G. Hildrew. 1998. The boundaries of river systems: The metazoan perspective. *Freshwater Biology* 40: 531–569.

Waters, T.F. 1995. *Sediment in streams: Sources, biological effects and control*, 251 pp. Bethesda: American Fisheries Society.

Welcomme, R.L. 1995. Relationships between fisheries and the integrity of river systems. *Regulated Rivers* 11 (I): 121–136.

Welcomme, R.L. 1979. *Fisheries ecology of floodplain rivers*, 317 pp. London: Longman.

———. 1985. *River fisheries FAO*. Fisheries Technical Paper No.262. UN Food and Agriculture Organization. Rome, Italy.

Wengert, N. 1980. A critical review of the river basins as a focus for resources planning, development and management. In *Symposium proceedings unified river basin management*, ed. North Dworsky and Allee. Minneapolis, Minnesota: AWRA.

White, R.J. 1991. Objectives should dictate methods in managing stream habitat for fish. *American Fisheries Society Symposium* 10: 44–52.

———. 1996. Growth and development of North American stream habitat management for fish. *Canadian Journal of Fisheries and Aquatic Sciences* 53 (Suppl 1) This issue.

World Commission on Dams (WCD). 2000. *Dams and development: A new framework for decision making. A report of the World Commission on Dams*. London: Earthscan. http://www.dams.org/report. Accessed 5 Sept 2004.

Zanoni, L., A. Gurnell, N. Drake, and N. Surian. 2008. Island dynamics in a braided river from analysis of historical maps and air photographs. *River Research and Applications (Published online in Wiley Inter Science)*: 1–18.

Zarfl, C., A.E. Lumsdon, J. Berlekamp, L. Tydecks, and K. Tockner. 2014. A global boom in hydropower dam construction. *Aquatic Sciences* 77: 161–170.

Zhong, Y., and G. Power. 1996. Some environmental impacts of hydroelectric projects on fish in Canada. *Impact Assessment*: 285–308.

Chapter 7
Ecobiopolitics, Policies, and Conservation Strategies of Rivers

Abstract Ecosystem health (**EH**) being an index in assessing the stability and productivity of an ecosystem integrates different research-based information as derived from the natural, social, technical, and health sciences. Based on such assessment, proper decision for sustainable eco-management incorporating human values and perceptions is possible. The developmental pace must be geared keeping parity with the ever increasing global populations so that alongside fulfilling the needs of the hour, carrying capacity of the resource bases should be kept in reserve to meet the needs and aspirations of future generations. However, some quite unsustainable development policies and practices, particularly concerning with water management, have been in practice during last couple of centuries. Economic and social change have necessitated development, sharing, and management of existing water resources based on sound environmental principles. A sound scientific understanding should form the foundation upon which rational decisions regarding water resources management should be made. Human beings are entirely dependent for their survival, heavily on clean continental water, including streams, lakes, wetlands, and groundwater. However, clean water appears to be a limited and precious resource for the future growth of the human population. Owing to the indispensability of good quality water resource, local problems with regard to the utilizing and sharing of water resources may lead to political instability.

As the economic valuation of clean water is difficult because of several reasons, several attributes are to be considered for assigning due importance and values of clean water for human use, for developing avenues for different fisheries activities, and for creating recreational setups on of aquatic habitats alongside utilization of water for direct human consumption. The global benefits of these uses translate into multibillions dollars while intangible benefits include sustainability of the ecosystem heath of the water bodies alongside conservation of aquatic biodiversity wealth and preservation of endemic and indigenous species. Ecological studies of fresh water system are expected to help taking sound decisions emphasizing on the socioeconomic perception of an area towards water management especially in view of ongoing human threats on inland water bodies In general, the eco-health of a river is reflected in respect of maintenance of steady higher environmental flows, stability of ecosystem and diversity of organisms. Such assessment of ecosystem tend to

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bridge up the gap of natural, social, political, and economical perspectives of environment so much to provide the definitive scientific foundation adhering to the ongoing scientific principles in maintaining social–ecological perspectives. This approach has also enabled to understand how its composition, organization, and functions remain relatively stable and sustainable over time.

Although, such applied analytical protocol enables to understand short-term human impacts and long-term environmental consequences. But in the dynamic riverine ecosystem, such assessment is more difficult than other ecosystems as there are hardly any fixed and stable conditions to refer to, and also due to the non-availability of undisturbed point of origin. Water recognizes no political boundaries which can restrict the environmental flows of the rivers but only the floodplains in the river basins and catchment areas having their unique topographic and phreatic limits of such catchments. Most of the large rivers of the world are subjected to artificial international or natural intranational boundaries. Therefore, resources of those transboundary rivers are shared among nations and states within nations.

Keywords Ecosystem health (EH) · Economic and social change · Carrying capacity of the resource bases · Political instability · Environment vs Development · Green growth · Economic model of Ricardo · Ecological adaptiveness · Ecological resilience · Environmental conflicts · River and Politics (Global and Regional) · Roles of ecological integrity in River rehabilitation programs · Interlinking of rivers in India · Sustainable river management

7.1 River Politics and Conservation

An international river, having no restriction in its movement, flows through the landscapes of two or more adjoining countries and thereby forms the boundary of the respective countries, with equitable sharing of resources especially water along with other living and nonliving ones. Some of the prominent rivers of the world having such international status are as mentioned below:

1. The river Nile draining four northeastern African countries
2. The river Amazon flowing through six South American countries
3. The river Zambezi moving through six southern African countries
4. The river Mekong, the prime river of The Republic of China connects five other south eastern Asian countries
5. Three major rivers of India, viz., Ganges, Brahmaputra, and Teesta sharing water the neighboring country, the Bangladesh
6. Another major river of India, the Indus, an important transboundary river shares water in two neighboring countries such as India and Pakistan

In Africa alone, 44 rivers along with their major tributaries not only constitute the boundaries of nations but also ensure water linkages among several countries. Such gifts vis-a-vis mercy of the nature endowed with historical legacies have made it

Table 7.1 Beneficial and adverse impacts of inter-basin water transfer projects

Some of the primary potential benefits of inter-basin water transfer include:
Economic growth
Improved livelihoods
Improvements in interregional relationships
Some of the primary adverse implications include:
Resettlement, dislocation or lack of relocation
Changes in river basin ecology
Loss of means of production
Loss of arable agricultural land
Loss of dry season grazing land
Changes in fisheries practices, fish life cycle and fish stocks
Sociocultural, socioeconomic, and psycho-physiological effects
Increased risk of impoverishment
Changes in household and community dynamics
Alterations in gender relations
Changes in natural resource access

difficult for the rulers, politicians, and administrators of the respective countries to settle the century old disputes in sharing the water and its resource base (Table 7.1).

For early societies, rivers acted as either major arteries facilitating the riverine flows or as obstacles, providing a ready defensive line in times of conflict. However, such anachronistic perceptions are not suitable in the this modern world where existing political boundaries because of the presence of such transboundary rivers along with their floodplains and watersheds are being considered as unfortunate historical legacies that considerably aggravate the problems of river basin resource management. Growing human populations are being considered as the prime factor causing rapid depletion of available freshwater resources in many areas of the world. The global human population has witnessed almost fourfold increase to become more than six billion during the span of last century and thereby appears to cause an eightfold increase of withdrawal of freshwater from the natural ecosystems during the same period (Gleick 1998).

In view of developing an unpropitious specter of increasingly acute shortages of water supply in many areas of the world, politicians, economist, environmental activists, social planners, and government leaders are very much concerned in finding out alternative strategies for sustainable water resources management (**IUCN** 2000). This effort is to be executed in such a manner so that the needs of water resources for the present generation is to be standardized and fulfilled along with ensuring with maintaining the reserve of the total amount of the water resources to meet the demand of the future generation. This quest for such sustainability can only be achieved by adhering to the basic principles of ecology and also by managing human uses of water in such a way that enough good quality water be available for the use of future generations. However keeping aside the importance of ecology, in the endeavor to manage water with special emphasis to ensure availability and supply to meet various human needs, several freshwater species and ecosystems have been considerably threatened along with generating other negative ecological consequences (Harper, 1998; Harper and Ferguson, 1995; Harper et al.1998; Naiman, 1997; **IUCN** 2000; Pringle et al. 2000; Stein et al. 2002; Baron et al. 2002).

7.2 Technology and Development: Planning and People

7.2.1 Environment vs Development

The term **development** has many different connotations. Development for the peoples meant to ensure better nutrition, health, education in order to enhance the ability and power to direct their own lives, enjoying freedom against oppression and poverty requires background information of environmental history and vision to meeting the aspirations for the future. Structural transformation of the present human society with their existing economy is hardly possible in the process of development not altering the prevailing relationships of dominance and subordination influencing the needs and interests of different groups of peoples within the society. The relationship between development and environment is the crux of the environmental debate in India.

People being a part of the environment are intimately linked to the air, water, soil, flora, and fauna forming a complex web of living and nonliving systems in the perpetual flux of ongoing ecological processes to sustain the process of life. The environment acting as the pool of resources promote for development, the prime objective of which is **Sustainable Development**, whereas growth is required to be oriented towards the paths of **Green Growth**. Even now there exists a number of misconceptions about environmental issues in the Third World. **First** misconception is that Third World Countries need “**development**” but without protecting nature’s ecological processes. **Second** misconception is closely related to the first, which states that poor people are seldom become a part of the solution of environmental problems instead of acting as the source and major cause of environmental problems.

7.2.2 Development and Environment

Development is not universally benign. Development for some means and targets under the developmental process lead to cause dispossession of many. Any development, for the environmental management of the water resource or controlling of the hazards, is a cornerstone of policy for developing world governments (Mascarenhas and Veit 1994; Veit et al. 1995; Zazueta 1995). This requires technology, based on nature, tradition, and perception of the society around the need to achieve the goals of development.

Environmental scientists, including hydrologists, are in need of less technology but more support from the society for their planning towards development. The concepts of integrated river basin management, ecosystem protection, and river restoration rest on the foundation of the "**grass roots**" realizations and well-designed programs involving the efforts of not only the engineers but also the ecologists, social scientists, economists and policy makers. The administrative costs of integrated river basin and watershed management within acceptable limits based on the affordability of the environmental policy makers and planners by delegating a large part of local management responsibilities to the local peoples who tend to play decisive roles (Bottrall 1992). Besides, any development along the riverine flows or in and around river basins certainly result different types of pollution mainly because of the application of so called traditional technologies in the urban sectors, roadways, dams, river bridge, several water intensive industries, etc. (Figs. 7.1, 7.2, 7.3, and 7.4).

All those human activities have appeared to be the leading causes of several aquatic pollutions such as eutrophication, deterioration of water qualities by persistent toxic chemicals, and all those ultimately lead to develop major climate changes. The probable consequences are not yet known with certainty, but it is clear that climate change would result in a redistribution of our water resources in time and space. To understand this change and be able to cope with it, the need of the moment is to develop much stronger scientific understanding of the processes involved.

The approaching problems, coupled with the many existing environmental stresses such as land and water pollution, erosion and sedimentation, and natural

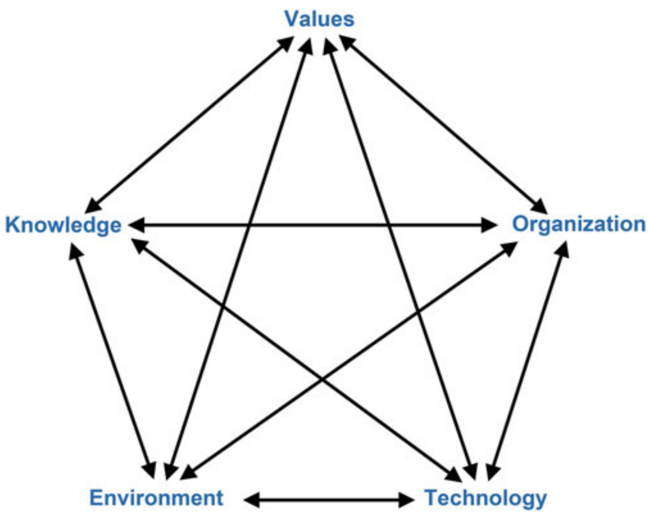

Fig. 7.1 Schematic representation of interconnection and interrelationships among different aspects of environment, technologies, and human development

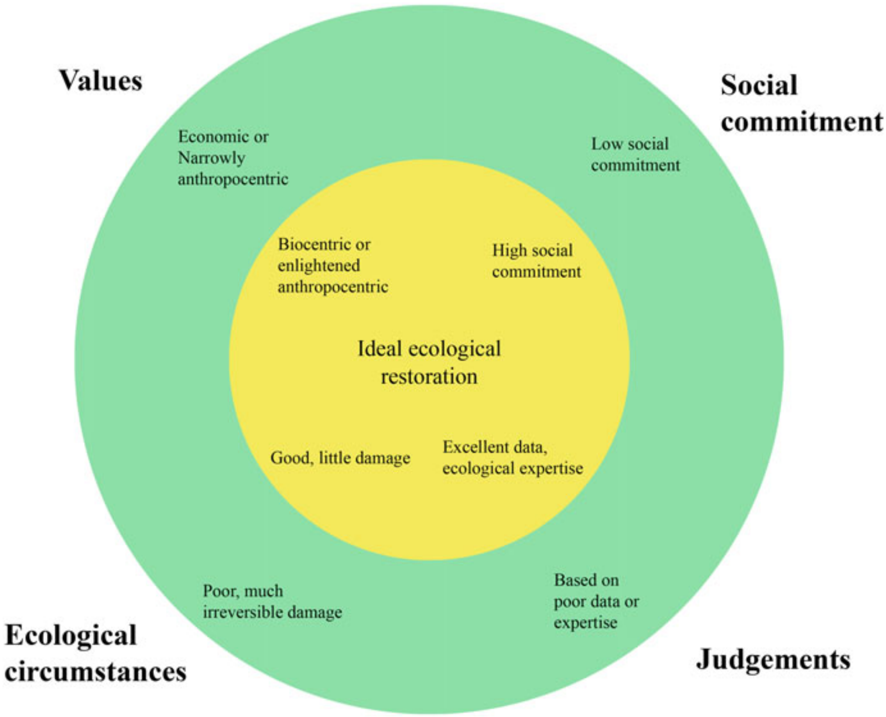

Fig. 7.2 Different facets of development and orientation of human environment relationships

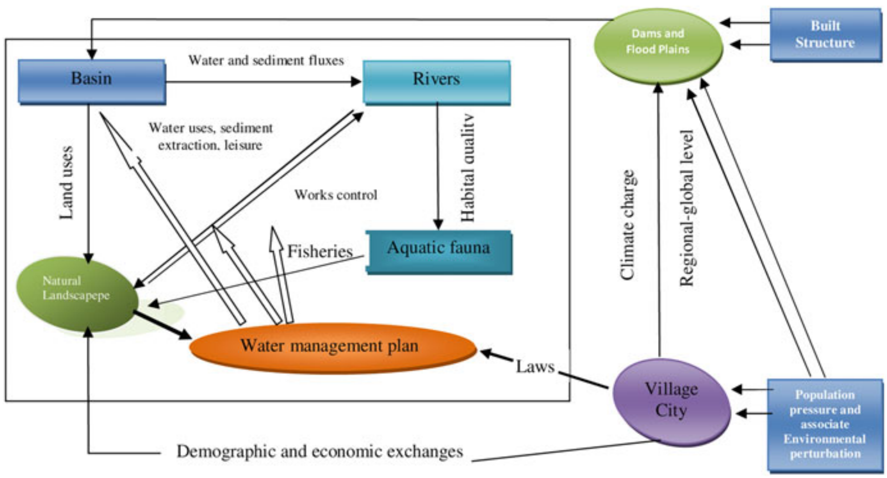

Fig. 7.3 Trends of imposition and intensity of impact of different factors (natural and anthropogenic) on river ecosystem

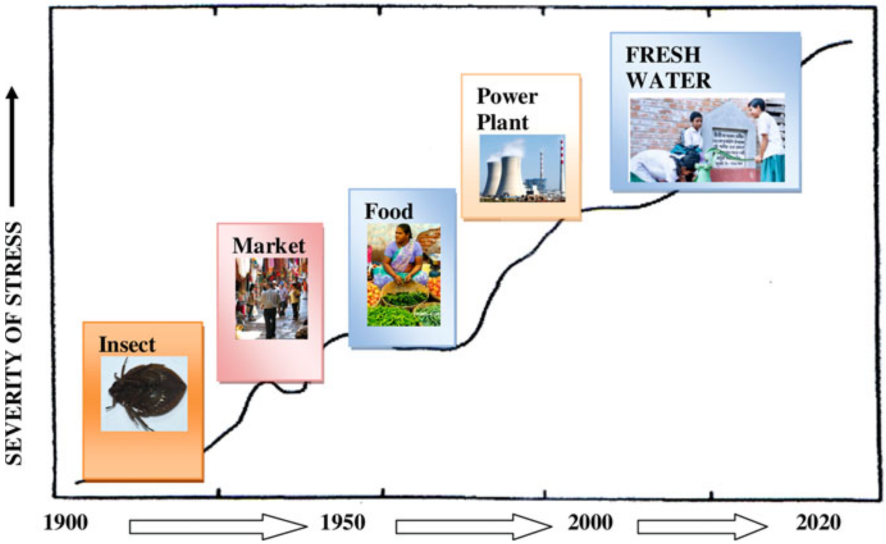

Fig. 7.4 Intermingling of different actors in demographic, economic, and ecological activities in the river landscape and resource utilization in different time scales

and artificial hazards, emphasize the need for continued development of human potentials, education, training, and public understanding as essential elements in a major international effort. The responsibilities of water scientists and engineers, with full consideration of the changing environment, are as follows:

1. To develop and maintain information on the availability of water resources
2. To assess, monitor, and predict the resulting quality of water bodies and water-related environment
3. To create a better scientific understanding of the effects of human activities that influence hydrological regimes (especially those resulting from climate change)
4. To provide decision-makers with the necessary information in properly constructed formats so that they realize the problems and the importance of the hydrological sciences as a basis for proper environmental management, especially of water resources so that they can react appropriately and take appropriate steps for sustainable water resource management.

The climatic changes and other ecological perturbations are the results of human developmental pathways and the probable consequent changes in the physical environment show that our present understanding of water resources and of the hydrological cycle is not sufficient. Prediction of new hydrological regimes will require a better understanding of the systems and a better capability for quantitative analysis than is now available.

More than ever before, decision-makers must be made aware of the importance of water problems, and they must be given recommendations for action based on sound scientific rationale. Hydrology and the study of water resources for sustainable development in a changing environment open a new era in the development of water sciences and management and are designed to provide an international focal point for a broad coordinated effort in hydrology and the scientific bases for water management.

They represent the combined efforts of national, regional, and international governmental organizations.

7.3 Major Causes of Threatening of Global Water Resources

Three major causes (Richter & Thomas, 2007; Richter et al. 1996, 1997; Pringle et al. 2000), leading to large-scale destruction of river ecosystem by drastically depleting the quality of water and the loss of biodiversity are as follows:

1. Alteration of river flow regimes associated with dam operations
2. Pollutants from nonpoint source pollution
3. Introduction, settlement, colonization, and flourishing of invasive species

In most of the cases, ecological services and products of freshwater ecosystem are threatened and damaged by disrespecting the sustainable water budget which determines the upper limit of the total amount of water to be withdrawn from freshwater systems so that the ecosystem functioning may not be hampered (Postel and Carpenter 1997; IUCN 2000). Politicians, administrators, technocrats, planners, and water managers in most of the time, especially in the developing tropical countries with tremendous population pressure, coupled with water scarcity pay least respect to the aquatic living organisms for their conservation. They are inclined to bow down on societal pressures which have been mounting steadily during last few decades to immediately solve water crisis problems by allowing withdrawal of huge amount of groundwater and abstraction of surface water from the river bed. However, several interpretations and hypothesis have emerged from different corners of the world with regard to the several conflicts and contradictions relating the demand of human beings for meeting their need of water and available water resources after sustaining so many human-mediated threats and odds impairing the balance between demand and supply, i.e., sustainability (Ritcher and Thomas, 2007).

7.3.1 Interpretation 1: Determining Human Influences on the Flow Regime

Humans are in need of water for multidimensional purposes including supply of water for municipal and industrial purposes, agricultural irrigation, generation of hydroelectric energy, culture of fish and other aquatic organisms, navigation, and recreation which result the modification of the natural flow of rivers.

Assessments of the nature, degree, and intensity of human influences on natural flow regimes should be performed for both current and projected levels of human use and expressed in spatial and temporal terms that are consistent with the definition of ecosystem flow requirements. Different short-term hydrologic conditions such as extreme low flows or floods impose tremendous ecological influence, the baseline information of which is being used to develop in hydrologic budgeting that record daily rehuman use and water availability for particular locations.

7.3.2 Interpretation 2: Identifying Incompatibilities Between Human and Ecosystem Needs

Best practice in water management is possible by comparing natural ecosystem flow requirements with the flow regime resulted after meeting human needs. Potential incompatibilities in between needs of human beings and requirements for the structural development of ecosystem temporarily and spatially scales should be assessed in each concerned river reach of concern, in the changing perspectives (degree, intensity, and nature) of conflicts from upstream to downstream, or across a watershed.

Quantification of the differences between human-induced flow conditions and needs for ecosystem functioning can throw light on the magnitude of the prospective and ongoing conflicts (Richter et al. 1996, 1997). Water managers, environmental planners and scientists, beneficiaries and conservationists are in need to find out ways of alleviating such conflicts, when human-influenced flow regimes are found to be incompatible with ecosystem flow requirements.

7.3.3 Interpretation 3: Sharing and Collaboration with the Stakeholders

After settlement of the issue pertaining to the potential incompatibilities in space and time, conflicts between human and ecosystem needs can also be explored, reduced and even be resolved through the sharing of relevant information and opening of dialogues among stakeholders. Fostering a collaborative dialogue among affected parties, making it far easier to build the consensus needed to develop and implement ecologically sustainable water management (Bingham 1986; Howitt 1992; Axelrod 1994; Rogers and Bestbier 1997). Human needs, desires, and preferences, including those pertaining to river ecosystem protection or restoration, should be expressed as a set of goals that collectively represent The stakeholder interests based on their needs, desires, expectations, and preferences of human being towards undertaking river ecosystem protection, conservation, and restoration measures determine the set of goals integrating the requirements of human beings with that of ecosystem. Some of the prime ecological needs in order to resolve these conflicts revolve on changing the timing or location of human uses towards greater compatibility with natural hydrologic cycles or the needs of the riverine biota, especially the native species to complete their life cycle and survivability.

7.3.4 Interpretation 4: Sustainable Development of an Adaptive Water Management Plan

The final phase of the framework is to achieve ecologically sustainability, where water management involves well-planned eco-monitoring coupled with carefully targeted research, and further experimentation not only to address but to overcome new uncertainties or difficulties. The environmental management approaches must also be continually modified in tune with the increased understanding or changes in human and ecosystem conditions (Fig. 7.4).

A number of hypotheses have so far been proposed concerning the expected responses of various ecosystem conditions to the ecosystem flow prescription which explained the sudden and distinct increase of fish diversity, abundance and production at specific ecozones within a river stretch after experiencing the impact of floods. Other hypotheses have also been validated by the recording and analyzing of monitoring data on different ecosystem indicators that reflect ecological integrity as a whole (Noss 1990). The design of built and concretized infrastructures for storing and releasing of water such as dams, barrages, etc. along with different hard and metallic accessories such as pipes, pumps, etc. which are used to divert water from a river, also pose difficulty in the management process. An ecologically viable and sustainable water management plan defends the ability to respond to new information gained from water management experiments or a long-term monitoring program.

7.4 Three Main Global Problems: Lack of Clear Policy

Severe global problems relating to large-scale deterioration of the quality and depletion of natural resources for present and future generations have been developed because of the absence of a clear policy for decision-making at different levels. Development is being thought as a socioeconomic political phenomenon, which mainly put emphasis on preferred certain environment/resource context with an eye to get more economic returns than to ecology. Judicious steps towards sustainable bioresource management including agriculture productivity based on natural life-support systems would call for a balance between political objectives and the function of such natural systems. Three prime global problems in the developing countries, concerning on land and water interactions are:

1. Eco-degradation of land and water over large areas in conjunction of population explosion
2. Dramatic changes of lifestyle patterns coupled with unplanned urbanization and industrialization
3. Serious water quality deterioration because of massive chemicalization of agriculture, lack of infrastructure for sewage disposal, and over-enrichment of water with nutrients (eutrophication).

7.5 Development-Mediated Ecological Perturbations: Role of River Ecology

The major manifestation of land degradation in most developing countries is soil erosion caused by extensive deforestation, overgrazing, and the improvident use of marginal lands for agriculture. The erosion of the top soil not only results in progressive losses of productivity of the lands affected but also takes a heavy toll of the economy in other ways:

1. It causes the premature siltation of irreplaceable water reservoirs constructed to support irrigation, hydropower production, low flow increase, and flood reduction.
2. Under conditions of better land management, the fresh water lost to the sea as floods could have been retained as groundwater and put to beneficial use in areas remote from rivers and water courses.
3. The uncontrolled waterlogging-mediated salinization of the soil has happened due to over seepage in permeable soils, and excessive application of water to lands which are not properly drained.
4. Waterlogging coupled with salinization tends to pose very serious threat to land resources especially because of the involvement of expensive modern high technology-based agriculture which tend to yield sustained production under good land and water management.

7.5.1 Urban Growth as Seen in the River Basin Perspective

The problem of urban growth, whether controlled or uncontrolled, poses massive challenges all over the world but particularly in the poor countries. Owing to lack of well-developed communication systems, and storages, the pressure on land and vegetation in and around urban areas has been increasing in an alarming rate in developing countries as compared to industrialized countries. Urban areas often occupy fertile lowland areas, forcing the local crop production uphills. Urban areas represent pockets in the national economy, where the demands on water may be quite high. Similarly, waste production, both solid and solute, is considerable. In industrialized countries, the urban water demand may create conflicts between domestic, industrial, and food production forces.

7.5.2 Water Quality Degradation

All over the world, water quality deterioration is an increasing problem. In industrialized countries, the pollution of rivers passing through urban areas is considered a large problem, and massive capital investments have gone into treatment plants and other measures to reduce the negative impact of point outlets on fishing and other beneficial uses of the river as a resource.

7.5.3 Economic Model of Ricardo

David Ricardo (1772–1823) introduced a second model of how economic activity relates to the environment (Fig. 7.5), not because he was concerned with environmental degradation or human survival but rather because he wished to justify why landlords received a rent from their ownership of land (Ricardo 1926). Ricardo argued that the people would initially farm the land that produced most food for the

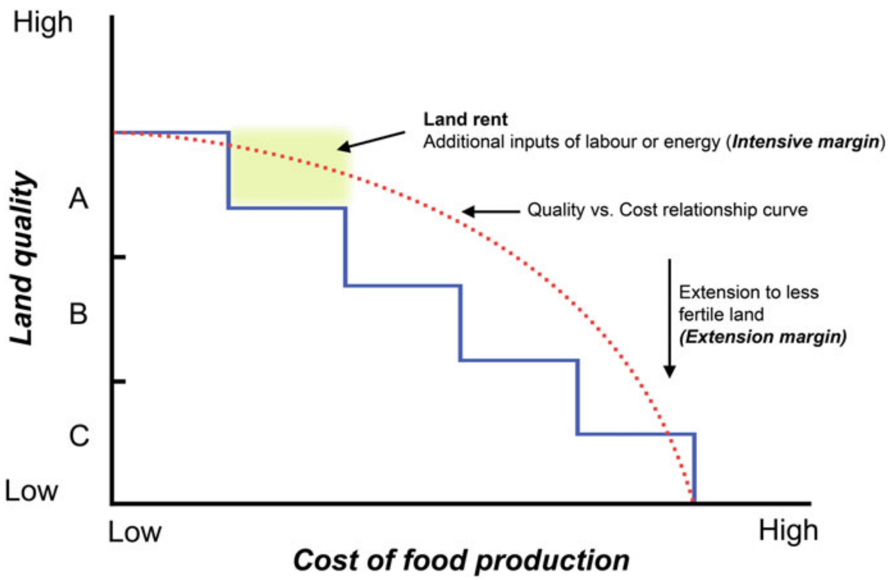

Fig. 7.5 Schematic highlights of Ricardo model projecting the relationship between land utilization and food production for balancing the cost effectiveness

least work. As population increased farming would extend to less fertile soils requiring more labor; economists refer to this additional land as the extensive margin. Higher food prices, in turn, would also induce a more intensive use of labor on the better land; economists refer to these additional inputs as the intensive margin.

Ricardo's model shows how increasing population drives people to farm in previously undisturbed areas and how higher food prices lead to intensified efforts, and in modern agriculture, the greater use of fertilizers and pesticides, on prime agriculture lands. Ricardo's way agricultural activities are patterned on the land in response to population growth and changes in food prices is critical to the understanding of the human beings towards complex interrelations between human survival and biodiversity.

7.6 Integrated Land and Water Management: Means and Approaches

Conservation and proper eco-management of the natural and continuously interacting life-support systems of land and water represent the greatest challenges of peoples all over the globe. This has become alarmingly acute in developing countries, like India because they possess several other problems such as poverty, increasing population pressures, and land degradation. A sound conservation and management policy needs to break out of this vicious circle and to pay more attention on the following:

1. Land use and soil quality may have great influence on water flow and water quality, and vice versa. The situation of serious land degradation in the developing world demands that there should be a clear recognition at all relevant decision-making levels in these countries of the imperatives of good resource management.
2. Land and water management are so inextricably linked with one another that the conservation and development of both these resources need to be undertaken in an integrated manner at all levels, from the field level to the central government.

7.7 Ecosystem Approach, Ecological Adaptiveness, and Ecological Resilience

7.7.1 Ecosystem Approach

The ecosystem approach helps develop guidance and management of complex ecological systems in order to solve problems due to misuse and mismanagement of the environment, but also to understand the outcomes generated out of the nature and influences of various manipulating steps taken by human being. The river basin includes a hierarchy of subbasins having different ecosystem components, especially in large-scale basins transversing the boundaries of different ecological zones. However, where river basin development focuses solely on socioeconomic perspectives such as merely for the development of water resources, the ecosystem concept might not suit for managing the water resources.

7.7.2 *Ecosystem Resilience*

An assessment of the response of different structural components of the river system against a multitude of ongoing perturbations has assumed great significance which can enable to record the trend and intensity of accumulation pollutants and eco-degradation. The emerging concept of ecological resilience pertaining to the eco-potential and capacity of an ecosystem to combat the ecological perturbations and also to absorb disturbance has appeared to contribute in chalking eco-management strategy not only to hinder the process of eco-degradation but also to recover the eco-degraded ecosystem (Holling 1973). An in-depth analysis of ecosystem dynamics emphasizing on ecological resilience is needed as an integral part of holistic eco-assessment and eco-management approaches approach-based resilience ability for eco-management is considered to be a capacity to "**absorbing, and recovering the impact as well as rebuilding post-disturbance**" (Namoi, 2013).

7.7.3 *Adaptive Management and Governance*

The eco-dynamism of running aquatic systems throw real challenges of understanding of the ecological processes and management strategies of the systems, despite having some initial success, achieving the goal of sustainable eco-restoration maintaining the ecosystem integrity has appeared to become very difficult despite consolidating all efforts of eco-restoration (Scheffer 2004). Attempts to tackle and combat the problems enunciated with ecological disturbances such flood, fire, storms, resurgence of pests, propagation of invasive species, etc. have often triggered the occurrence of more profound and disruptive changes in the ecosystem (Sendzimir et al. 2008; Gleick 2002; Pahl-Wostl et al. 2007). Eco-management of river ecosystem requires assessing of human impacts with sustained capacity following holistic approaches for unearthing baseline information relating to the trend of ecological changes and also to comparing the understanding with the controlled undisturbed reference sites and also by adopting flexible management strategies giving due importance on socioeconomic–cultural–political aspects of human intervention.

7.8 Criteria and Action Components in an Environmentally Sound Management of Land and Water

As water and land of any riverine system are interexchangeable components of nature, they tend to remain always closely interrelated to each other and at the same time always render influence on the water flow, seasonality and water quality which have necessitated to undertake integrated planning of land and water conservation, giving emphasis on the geomorphological and ecological characteristics of river drainage basin. On the other way, both water and land interventions by man, result changes and alterations in the natural environment. In such context, a holistic approach towards environmental protection should be undertaken keeping aside any isolated activity and thereby justifying the approach of providing much stress on another side of the same coin.

Such pro-ecological and realistic approach for sound land and water management avoiding harmful environmental alterations can certainly result sustained productivity of the resources, implying the harmonization, environmental development, and socioeconomic interests in a river basin. However, it is imperative to ensure to maximize the availability of water, alongside conserving the same precious resource base for maximizing socioeconomic benefits in the river basin. The interactions and conflicts between rural and urban areas should also be taken care off in the framework of the carrying capacity of the river basin based on the of the ecological characteristics of water and soils. Transbasin water transfers may reduce the importance of the drainage basin as a relevant terrestrial unit. The water divide, however, remains as a natural membrane, in some respects separated from outer environments although passed by import/export flows of water and other goods.

7.9 Conservation Efforts: Does the RCC Have any Utility in Asia?

Information pertaining to River Continuum Concept (**RCC**) mostly derived from the long-term research on the rivers of temperate countries where catchments are dominated by temperate deciduous forest species and climatic factors mostly dominated by cold temperature coupled with snow falls impose different eco-physiological stresses on aquatic biota and ecological processes in comparison to its tropical counterparts. The functional organization of zoobenthic communities among different Asian streams and rivers differs to a considerable extent disobeying with the predictions of the **RCC** of temperate regions (Vannote et al. 1980). Multifunctional studies with proper quantification of functional organization of benthic communities and its longitudinal changing patterns along several pristine Asian rivers are lacking but such research-based information are very much needed. In such research, efforts inclusion of fish communities in respect of their diversity, population density, and biomass, along with changing patterns of various feeding groups, in the longitudinal flow gradients during dry and wet seasons will increase the usefulness of such comparison. Nevertheless, without such research, Indian rivers experiencing variable ongoing environmental perturbational effects of human activities, it is confusing and uncertain whether **RCC** can contribute anything appropriate for conservation measures. Conservation of particular species mostly depend more on different eco-biological information of the target organisms and less on a general understanding of ecosystem functioning. Fishes in the Asian rivers exhibit complex life cycles and flexibility in choosing different habitats at various stages of their life cycle, exposing themselves to many routes to toxic pollutants, direct harvesting, and other detrimental inputs.

For such varied reasons, emphasis has been laid on to identify flagship species and keystone habitats which are supposed to invoke much public and government awareness towards the conservation of the target species in particular and existence of aquatic biodiversity in general. Effective habitat conservation will require prior awareness development program in tune with the socioeconomic–political–cultural spirits of the local peoples relating to the benefits to be gained from the integrated use of floodplains, rivers, and riparian habitats instead of their conversion to other uses. Habitat destruction and even fragmentation make so many indigenous species homeless, and those resident populations are ultimately pushed towards extinction.

7.10 Conflict Management: Tools and Principle

The applicability or non-applicability of "**the river basin approach**" from the institutional point of view is required to emphasize on the energy budgets for ensuring targeted development within the river basin. Three functional and territorial interjurisdictional problems are in need to be addressed:

1. River basins in the national (non-shared) perspectives
2. National shared river basins (interstate or interprovincial rivers) in national (shared) perspectives
3. International river basins in international perspectives

Legal tools needed to reach resiliency in the use of waters following changes in land and water use patterns have been developed.

7.10.1 Global Legal Perspective

Obviously, every river basin is defined by the Nature as an unit in which the waters – and in a lesser degree – the air, and the natural resources which produce interaction with and among the other natural resources, especially land, flora, and fauna. The physical aspects of water (fluid) and air (movable) determine and serve as elements and factors of primal influence in the river basin ecosystem. The institutional problem (and legislation is an institution) arises frequently when the geographical or territorial area of a basin does not coincide with the physical boundaries over which the political institutions have powers. However, an entire river basin under only one political jurisdiction may not function properly, due to the inadequate local political institutions But the interjurisdictional conflicts can take place among (**a**) two or more independent states/countries but certainly falls within the jurisdiction of International Law; (**b**) two or more political subdivisions of one independent state/country (provinces, states, etc.). Based on the realistic ground truth information propitiating the administration of waters and connected natural resources by river basins, the Government of a country cannot become a Confederation of river basin agencies. The legislation, and the organization of the administrative institutions are assumed as the only tools or political instruments instead of ending any purpose to an amicable settlement. Therefore, subpolicies for each river basin must be included in the general policies of a country, starting with that which refers to water resources.

7.10.2 When the River Basin Approach Is Left Aside?

Some uses of the water resources, or of the goods produced with them, can take place outside the river basin of origin, i.e., a transfer of water to a different river basin or the transmitting of electricity generated in a river basin for consumption in another river basin. The economic, social, and political effects of the usage of said natural resources-based commodity are thus expanded farther than the boundaries of its original basin. This involves also the need to expand the territorial action area of the responsible administrative organization, although only in as much as it concerns the corresponding specific subject (water or electricity provision). Some people object to the fact that international law does not bind to adopt the river basin concept (Bourne 1976; UNDP 1975). The transfer of water from one basin to another creates particular jurisdicsal problems. Generally it requires consent from the people of the areas who might be deprived of present trend or potential usage of the water and acceptable compensations may consequently be called for. The functional contribution of surface and underground river basins sometimes differ deviating from the point of convergence in respect of their potential as water sources.

7.10.3 The Regional Perspective

In the cases considered above, the river basin approach has been substituted by that of region. Water may cease playing a role as an interdependent natural factor, but it can be used as a tool to induce interdependency both physically and economically and even politically. Some countries which adopted the river basin authorities system, where there are many small and neighboring river basins of similar physiographic and sociological characteristics, it is better to consolidate in a single agency for the management of said various small basins, due to administrative "**scale economy**" reasons as practiced in a country like France (Teclaff, 1967).

7.10.4 *Energy Considerations: Independent of the River Basin Approach*

Energy is the natural resource determinant of the very existence of human life. It is linked to the existence of the biotic natural resources and to the feeding chain and to the inert resources. Energy is linked to entropy and the explainable human desire to prolong life as much as possible and that of the planet we inhabit has to do with the use of energetic sources which produce low entropy. This can certainly be obtained within the boundaries of a river basin, but it is not subject to said limits, and therefore the role of the energetic factor can be and must be contemplated at nationwide scale and even at planet wide scale.

7.10.5 *National Perspective of (Non-shared) River Basins*

A river basin can be managed in various ways: (a) under an ad hoc regime, (b) under a normal or common administrative regime (ministerial or departmental) existing in the country.

7.10.5.1 Population Growth and Technological Progress: Impact on Land and Water

Since the earlier periods of the twentieth century, both the rapid population growth as well as the technological progress have been imposing considerable impacts causing frequent, steady and even drastic alterations in the land-use patterns (Figs. 7.4 and 7.5). The growth of cities and consequent water requirements for domestic and municipal use generally takes place at the expense of waters previously allocated to agricultural uses and subsequently industrial sectors share a large part of water resources. Urban as well as industrial uses synergically increase the water pollution diminishing availability of water for agricultural purposes.

Water used for hydroelectrical generation further aggravate the water budgeting. Recreation uses of high social value, mostly on the development of tourist industry make other uses problematic or impossible, especially if the pollution takes place upstream. Considering all those factors putting pressure on water budget, two legal institutions have appeared to become bottlenecks, namely, (**a**) the rigid and permanent allocation of water to specific uses, thus producing vested rights which must be respected, or compensated in the event of a deprivation. (**b**) The standing rigid priorities system between conflictive uses or users. Conflicts which would originate among the various ways of usage or among different users, or even in connection with other natural resources (for instance, hydroelectrical generation **vs** thermoelectrical generation; i.e., water **vs** petroleum).

7.10.5.2 National (Shared) River Basins

In certain federal countries, the problem of adopting a river basin approach originates when river basins are shared by more than one of their internal political subdivisions (states, provinces, cantons, republics). This is the case in Argentina, Australia, Canada, FR Germany, India, Switzerland, and the **USA**}. In other federal countries (Brazil, Mexico, the **USSR**, Venezuela, etc.), the central government of each country has the necessary power to solve such conflicts, or the rivers are simply under the full national authority and, therefore, territorially based interjurisdictional conflicts do not exist.

Two alternative solutions have been used among the countries which belong to their respective groups based on some similarities which are as follows:

1. The celebration of agreements, treaties or compacts between the political entities are to be involved to achieve resolution. In the **USA**, said "**compacts**" require consent by the National Congress, something which involves the Federal Government in the negotiations as an interested party.
2. Judiciary decision of the controversies when such agreements are lacking, in the country's Supreme Judiciary Courts as in the countries like Argentina, FR Germany, Switzerland, and the **USA**. In India, where the Supreme Court lacks such attribution, they resorted to the creation of **River Disputes Boards** which are to prevent conflicts but which must be consented by the states involved. It has become customary that all such dissentments must be resolved by an arbitrator who is to be nominated by the Supreme Court of India. Simultaneously the **Interstate Water Dispute Act** in India establishes a procedure for solving already formalized disputes, which excludes from its regime the case of the rivers where **River Disputes Boards** exist.

7.11 Environmental Conflicts: Structure and Management

Biological, materialistic and psychological attachments and possessiveness on riverine natural resources, both physical and biological imply human interventions to not only safeguard the existing ones but also prevent deteriorating qualities of the natural systems. The ever increasing demand on natural resource bases, mostly of water have led to develop intensive conflicts and competitions within the local or regional frameworks utilizing the unconventional but highly rational and efficient. Methods within the political and social systems which have been assuming greater importance based on the incompatibility of interests, goals, principles, or norms of the parties involved in several countries,

7.12 Claims, Demands on Water and Power to Get Access to It

Nobody owns the water. People may only have the right to use it according to certain provisions. In most countries water issues are regulated by a large number of laws and regulations, and administratively they are handled by several departments and agencies. Considering the flow of water within the limits of river basins, there are two main difficulties. One arises from the fact that administrative and natural boundaries do generally not coincide. Administrative and legal bases of division are usually not based on physical properties of a landscape. Another difficulty is related to the mutual influence between land and water utilization, a complexity which is rarely considered in terms of coordinated legislation or planning. The water within a river basin is held in common by the nations/states/communities, etc. involved. In most cases, there is a common interest in finding a solution to the different problems. The overall issue tends to generate the tension between the specific interests of the individual users which in turn generate necessity of collective measures for the protection from the indivisible effects of individual exploitation. The qualitative properties of water undergo changes because of several natural and anthropogenic factors.

In natural flows, water is used as a solvent for the transportation of substances. Land can be put to a variety of uses and thereby causing changes in the quality of the passing water (Karim et al. 1995). Water is consequently a connecting link between various activities and land-use patterns (agriculture, industry, recreational facilities, etc.) and between society and the natural environment. Man demands water to satisfy various biological, material, and psychological needs such as clean drinking water, irrigation, and possibilities to recreation. Conflicts may arise in connection with practically any intervention in the natural system. The various interested parties differ in their viewpoints and consequently employ a variety of arguments and lines of action in making claims on the water resource. **Conflicts over water tend to mobilize a very high degree of energy and to be very intense in character, probably because actors and group members are deeply involved with one another and highly dependent on the water supply** (Falkenmark, 1981).

7.12.1 Relationships Between Upstream and Downstream Uses of Water

A non-consumptive upstream use may involve a degradation in the quality of water, and the downstream user may not be able to use that water. Likewise, activities downstream might lead to harmful results, such as flooding, upstream. Another potential conflict area is when water demand and use in the urban areas may cause conflicts with the needs of water for irrigation in the rural area. With increasing demands for water for various purposes, conflicts between different states sharing the same river basin or aquifer and conflicts between different nations are on rise and are expected to intensify further in the future. Access to and the right to use or not to use the water are political questions. Each conflict includes a number of actors whose values and interests are incompatible. The actors (formal, through legislation, and informal, through well-established practice) may operate at the local, regional, national, or international level, on arenas of various dignities.

7.12.2 The Structure of Conflicts

A classical definition of a conflict is given by Kenneth Boulding: "**Conflict occurs when two or more people believe they have mutually incompatible goals**" (Boulding 1963). Conflicts can be seen as compound processes and to describe them empirically means a generalization of certain characteristics by analyzing their dynamics (Tagil 1977). A fundamental assertion is that conflicts are not necessarily static or uniform over time. Expanding the concept of water conflicts to **environmental conflicts**, it can be stated that environmental and resource conflicts are both multiple and complex, around overlapping sets of problems (Wehr and Throp 1997; Wehr and Jean-Pierre Descy 1998). Often there is a conflict over visions of the future, something which is often difficult to pinpoint (Falkenmark, 1981). The field of conflict management lacks a standard body of knowledge for training peace-makers. Fragmentation characterizes conflict management theory, "... **and only the smallest part of that which does exist has been applied in environmental dispute settlement**" (Wehr 1979). Moreover, primacy of jurisdiction or interpretation of law may not be established, long-range effects may be uncertain, and decisions may be irreversible (Moore 1982). Despite all this, it is important to have in mind that conflicts might be productive producing new standards and new patterns of relationships. Different forms of conflicts arise as mentioned below because of multifarious uses of water within sectors such as agriculture, industry, fishing, energy, nature conservation, recreation, etc. which together or independently put irreconcilable claims on water.

1. Quality conflicts: far-reaching claims on water quality as opposed to recipient claims.

   When one activity makes water unfit for use in, or causes damage to, another activity:
2. Preservation conflicts – claims for intervention in the water system as opposed to claims on undisturbed nature

3. Quantity conflicts – when one use makes difficult/prevents another use, i.e., urban water use makes difficult/prevents another use, i.e., urban water supply as opposed to irrigation
4. Mixed quality or quantity conflicts

These conflicts often become more complex through the balancing of the political and other kinds of goals against one another. Water conflicts do often involve political, economic, and social interests, such as employment, in opposition to interests which are difficult to measure, such as scenic beauty. Even if water, or more broadly environmental, issues have strong political consequences, they do not attract political priority unless there is a feeling of crises. In many industrialized countries where growth and expansion are the driving principles, environment has never been a primary issue; it is always a kind of backdoor issue. Concern for development and environment are like a seesaw, they never run parallel with each other. States and nations do often have different political strength, in terms of power, and the levels of economic development may also differ. This leads to very complicated conflicts. This is true all over the world, within river basins in Asia as well as in Africa or the USA.

7.13 Environmental Conflict Management

In order to address the problems pertaining to conflicts on sharing or uses of water along with its other waterborne resources an infinite variety of mechanisms for conflict management are in operation all over the globe. Proper understanding of the differences of mindsets and approaches among different actors at different levels in legislation, in political, economic and social prerequisites, in the administrative structure, traditions, and valuations are important in solving those conflicts. Methods and instruments for conflict resolutions vary; from uncomplicated agreements to very formal, heavy international treaties; from settled diplomacy to unconventional negotiations. It is to be assumed that the intention with water legislation is to pursue an allocation that guarantees that usage leads to a maximum of benefit for individuals as well as for the entire society. Wehr (1979) discusses conflict management through environmental policy planning. It is an approach stating that meaningful participation of citizens in the various stages of planning is the most successful way of resolving and sometimes even avoiding policy conflicts. Planning occurs in three stages: (**1**) policy analysis, (**2**) policy determination, and (**3**) policy implementation.

7.14 Ecological Theory for River System Management: A Theory of Ecosystems

The Ecosystem approach is defined as an anticipatory approach to planning of river basins in a holistic manner integrating all the structural components of the ecosystem. It is based on the knowledge of the operation and interrelationships of systems in nature and, in consequence, the necessity of ecological behavior and desirability of adoption of an ethic of respect for other systems of nature. Therefore this approach varies in temporal and spatial scales. Ecosystems being natural subdivisions of the biosphere, are provided with boundaries defined with a view on the socio-political perspectives to suit particular purposes on hand. More realistically, ecological systems are interacting assemblages in which any two elements affect the third. One element cannot be modified without changing the other two.

7.14.1 Ingredients for an Ecosystem Approach

Improve knowledge of the operation and relationships of systems in nature. Develop a holistic perspective that takes account of the influences on us of larger systems of which we and our external environments are parts. Act in ways that are ecological (take account of that knowledge and perspective), anticipatory (forestalling events that would bring later regret), and ethical (showing respect for other systems of nature comparable to mode of respect exhibited by human beings to other persons). In the past, there has been too much focus on hierarchical structures and intraorganizational concerns. However, an evolution of several management approaches and methods developed integrating different eco–bio–geological components with an ecosystem approach for development.

1. Organic waste are needed to disposed in much more eco-friendly manner at suitable places keeping in mind the downstream problems and are subsequently processed by the innovative energy-consumptive sewage treatment systems. Developed with an ecosystem approach focusing on energy and material recovery from sewage.

2. Eutrophication of water is required to be identified at the initial stage, especially before the development of strong odors, within the nutrient rich effluents which flow to the downstream. At the site of eutrophication, undermentioned two ways approaches should be followed:

(i) Removal of phosphorus from sewage effluents

(ii) Adoption of ecosystem approach which advocates reduced use of low-phosphate detergents and more efficient use of fertilizers combined with nutrient recycling.

(iii) The problems of acid rain because of the deposition of different oxides of chemical elements from the industries can be solved to some extent by building up taller smoke-stacks and also acids can be removed by scrubbing. Such eco-friendly approaches also advocate the recycling of sulfur (S) and conservation of energy.

(iv) In order to ensure water diversions and consumptive use, two rules are framed where the first emphasizes the diversion of water where the second focuses in developing scales to meet new shortages, encouraging export as a commodity.

(v) Indiscriminate usage of toxic chemicals is to be dealt with one by one applying the existing regulations as applied in the case of pesticides.

(vi) Developing an ecosystem approach requires the need of designing the management strategies giving due emphasize on the chemical properties of the compounds especially for the persistent and long-lived compounds.

(vii) Successive solutions in respect of energy shortages are taken care of ignoring the problem, instead of increasing the energy supply and expanding the grid in a cost-effective manner to encourage more uses.

(viii) In order to control the pests, initially broad-spectrum pesticides were used which were subsequently replaced by the selective and degradable poisons. Presently the ecosystem approach involving the integrated pest management has become very much popular.

7.15 Ecosystem Approach to River Basin Management

The river basin is an ecosystem subject to multiple use. The geomorphologist, the hydrologist, the social scientist, and the climatologist can all contribute to such ecosystem approach to river basins. It becomes necessary to have an integrated approach. The river basin provides a natural boundary to evaluate the ecosystems contained therein. A watershed or catchment is an integrated system that transforms precipitation, solar radiation, other environmental variables, labor, and capital in forest products, livestock products, wildlife, recreational, and aesthetic satisfactions, and water. The only level of ecological theory that can effectively guide management of such complex systems is a theory of ecosystems.

It is based on the knowledge of the operation and interrelationships of systems in nature and, in consequence, the necessity of ecological behavior and desirability of adoption of an ethic is developed in respect of other systems of nature. The attitudes, perceptions, and behavior of people and organizations in river basins have been shifting over the past decades from an environmental approach to an ecosystem approach for planning and problem-solving. The ecosystem approaches have to form an integrated transdisciplinary research and management strategies for rivers and river basins bridging different disciplines of natural and human ecology to taking into consideration of the following:

1. Concepts and methods of appropriate spatial and temporal scopes: For wide scale and detailed analysis
2. Analytically, sufficient specification of the ecosystem with respect to external natural processes and components, internal natural processes and components, and ecosystem man–nature interactions
3. Holistically, adequate comprehension of internal evolutionary and successional process, in response to the adaptiveness to external factors, as well as recovery sequences after relaxation of external stress
4. Information set includes maps of spatial ecosystem features, with monitored time series of diagnostic features, models of relational or causal processes, to be used in management cost studies
5. Management objectives involve compromises with respect to material well-being/progress, cultural opportunity/equity and environmental harmony/ethics
6. Political-administrative processes include the active involvement of a broad representation of users of the ecosystem so that implement a range of legal economic mechanisms designed to reduce user stresses, regularly and critically review the planning, regulatory, and budgeting functions of all agencies involved in the management of the ecosystem
7. Disciplines/professions include ecologists/geographers/economists/political scientists, and also engineers/planners/environmental-resource managers.

It can be concluded that it would be neither possible nor desirable to specify a unique, unitary, unified universal **ecosystem** approach to river basins. The seven features above tend to complement each other, as do their subfeatures. Any practical attempt to be effective will need to deal with some of those criteria in a dialectal way or seek some pragmatic compromise. By the river basin strategy, a harmonized new environment should be developed in connection with the water projects. All those abovementioned highlights lead to the following recommendations:

1. The river basin strategies should be analyzed in connection with the river basin development process.
2. The interactions between the river basin strategies and the growing complexity of water management during the river basin development process need to be harmonized over a long-term basis by considering the projects as an integrated element of the water management system of the basin.
3. The evaluation and the planning of river basin strategies need the application of the multicriterion decision-analysis methods, including the environmental impact and management analysis as an integrated element of the decision-making process.
4. For medium and large river basins, there is often a shortage of capital resources. Regional or interregional multipurpose water management systems should therefore be developed gradually and over a long time horizon.

Considering that most of the river basin strategies, it is the necessity to change the natural and social environment to a certain extent. The main objective of any water project should be to develop a new equilibrium between the project and its environment by the harmonization of the original environmental conditions and the project impacts.

To achieve this goal, the development of environmental monitoring system should be an integrated part of the river basin strategy, and it should be initiated from the planning phase.

7.16 River and Politics: Conservation Strategies

Rivers exist to carry water to the sea, and they develop channels to maintain their normal flow. The form of the river channel affects the flow of water in it, and, through erosion and deposition, the flow acting as a jerky conveyor belt for the intermittent movement and transport of alluvium is moving seaward (Ferguson 1981).

7.16.1 Sustainable Management of River Basin Systems

Sustainability in river basin management cannot be ensured by several ongoing attempt of developing interstate and internations rivers linkages in order to make equitable sharing of water resources by way of imposing administrative controls. It is noted that the idea of river basin authorities attracts a lot of attention. In practice there are, however, a lot of circumstances which impede a proper realization of such authorities. Inter-basin transfer of water or long-distance transfer of energy from hydropower plants will transcend the division of entities based on the water divide and is mostly dependent on river systems engineering.

Administration of the geographical regions of basins also depends on the contemporary socioeconomic–political setting in industrialized countries influenced by urban-oriented policies and analyses. Regional development thinking in developing countries is obviously to a large degree based on a realization of the close interrelations between land and water resources in a river basin perspective. Systems could have been grouped by latitude, climate, flow regime, topography, degree of anthropogenic disturbance, floodplain development, and so on. For example, three of the systems are allogenic, arising in humid, mountainous terrain and flowing over most of their lengths through semi-arid to arid terrain.

7.16.2 Preservation of River Systems vs River Dynamism

The fundamental physical integrity of river basins must be respected by any management scheme which claims to be long term. River and stream ecosystem structure and function are controlled by energy source, quality of water, flow regime, and habitat structure. Besides, a holistic approach towards conservation and restoration of river channels and adjoining wetlands is required. Policy responses towards such research efforts should take into consideration the following points in view of widespread human impacts on hydrological characteristics: (**a**) deforestation, (**b**) irrigation, (**c**) urbanization, (**d**) river regulation, and (**e**) use of agricultural chemicals.

The major river basins perform a kind of smoothing process on the hydrological signals from individual anthropogenic activity. One activity is rarely performed in isolation, and the hydrological characteristics at a basin outlet are an integration of the effects of different activities operating at different scales (Arnell 1989). The policy maker has, therefore, some excuse for confusion: either land-use effects are confused and overlapping or clear or the source of an insidious chain of **knock-on** deteriorations in the river environment. The key to the confusion is twofold: first, land-use effects are regionally adjusted in their impact by major variables such as climate (forests behave differently in wet, dry, and snowy climates) and second, their impact will depend on the sensitivity of the river basin resource system considered (in relation to the degree of control on basin behavior already exerted by climate and water management).

7.17 Land-Use Planning: Prerequisite for River Basin Development and Eco-Management

To develop an influential position with regard to land-use planning, those concerned with river basin management have a tough problem. There are two essential prerequisites of policy information before investigating the uptake of hydrological guidance in land use and land management as practiced in developed countries. **(a)** Rural land-use policy is not achieved directly but by market interventions for produce or incentives offered by the Common Agricultural Policy of the European Communities. **(b)** In outside towns, there are little land-use planning, exceptions being national parks, and land for nature conservation. Owing to all round development all over the world, the problems faced by those developing river basin resources in a "**developing**" country are no different to those in a "**developed**" country. The problems of water development in the developing world surround are being summarized as follows:

1. The least developed countries
2. The dry lands and their wetter hinterlands, often mountains
3. Major international river basins
4. Inter- and intranational political tension
5. Institutional problems of integration and application

In the developed world, outside dry lands following problems are encountered:

1. Pollution controls permissive to further development

2. Hazard management
3. Recreational and conservational priorities
4. Problems of inadequate data; decisions must appear rational
5. Institutional problems of integration and planning

However, since integration, planning, and application issues are genuinely interdisciplinary, the involvement of researchers and planners across the disciplines, both natural and social sciences to intervene and to chalk out proper management strategies. The real issue, therefore, of sustainable river basin management, wherever it is required, is that of the application of knowledge against an informed perception of the enormity of the integration required. Holistic thinking has a special, almost visionary role in helping politicians and people understand that rapid "**fixes**" are impossible but that strategies can and must "**keep us on the rails**."

7.18 Major Thrusts of Conservation

The subject conservation biology takes into consideration different facets of the conservation of threatened flora and fauna emphasizing the causes and consequences of biodiversity loss and is considered as crisis discipline (Soule 1985). In such context, the blending of the conceptual framework with the standardized technological tools is utmost necessary for perceiving and identification of the problems, recording of the baseline information, interpretation of data and taking appropriate actions to ensure conservation (Levin, 1992). However, determination of the proper timing and process of human intervention in nature has appeared to be rarely consensual (Hobbs et al. 2011; Simpson & Norris, 2000). In such circumstance, not only space but also time in number of generations (Gould 1995) should be considered in order to understand the mode of occurrences, abundances and distributional patterns of species.

It is also necessary to determine timing and levels (from genes to the ecosystems, through the different hierarchical stages like individuals, populations, communities, and ecosystems) such intervention on nature be made for not only identifying the causes of biodiversity loss but also for solving the problems of. Conservation biology has long been focused on the species distribution, biodiversity, and abundance patterns (Mittermeier et al. 1998) and, more recently, as **genetic evolutionarily significant unit** (**ESU**) operating at molecular level (Moritz 2006). This later approach for undertaking conservation measures relies more on characterizing intra- and interpopulation genetic variation. The outcomes of such effort also help in developing and standardizing new methodologies that enable to minimize the variability loss of genetic variability by protecting and preserving the existing gene pools (Stoeckel et al. 1997).

However, maintaining biodiversity is only possible if the preservation of the biodiversity patterns adds the protection of those processes that maintain, sustain, and generate biodiversity are added (Rouget et al. 2006). It is an acceptable notion across the world that a combined roles of both ecological and evolutionary processes in determining genetic variation having adaptive significance can develop efficient conservation strategies (Crandall et al. 2000), even in relatively short period of time (Levins 1969).

7.19 Geomorphic Perspectives on Ecosystem Approaches to River Management

Rivers are continuously changing ecosystems that interact with the surrounding atmosphere (climatic and hydrological factors), biosphere (biotic factors), and earth (terrestrial or geological factors). Increasing recognition that ecosystems are open, nondeterministic, heterogeneous, and often in non-equilibrium states is prompting a shift in management away from maintaining stable systems for particular species to a whole-of-system approach which emphasizes diversity and flux across temporal and spatial scales. Working within an ecosystem approach to natural resources management, river rehabilitation programs apply multidisciplinary thinking to address concerns for biodiversity and ecosystem integrity (Sparks 1995). Inevitably, the ultimate goals of these applications are guided by attempts to balance social, economic, and environmental needs, and they are constrained by the existing hydrological, water quality, and sediment transport regimes of any given system (Petts and Amoros 1996).

7.19.1 River Rehabilitation Programs: Roles of Ecological Integrity

River rehabilitation programs framed in terms of ecological integrity, must build on principles of landscape ecology. The landscape context manifests through the geomorphic structure and function of river systems, which provide a coherent template upon which these aspirations must be grounded. The challenge presented to geomorphologists is to construct a framework with which to meaningfully describe, explain, and predict the character and behavior of aquatic ecosystems. Both the prevailing physicochemical and biological integrities together act to develop and maintain ecological integrity at an appropriate level of connectivity between hydrological, geomorphic, and biotic processes. Totality of the system is touched upon by the biological integrity involving all biotic elements along with all ecological processes and interactions at appropriate scales and rates (Angermeier and Karr 1994). This records a system's power to produce and maintain several biotic elements along with their adaptability through the natural evolutionary processes.

In riparian landscapes, aquatic, amphibious, and terrestrial species have manifested different forms of morpho-anatomical characteristics to get themselves adapted a to a shifting mosaic of habitats, by way of exploiting the habitat heterogeneity that results from natural disturbance regimes (Junk et al. 1989; Petts and Amoros 1996; Naiman, 1997; Naiman and Decamps 1990; Ward et al. 2002). This mosaic of habitat heterogeneities includes surface waters, bottom sediments, alluvial aquifers, riparian vegetation associations, and different other geomorphic features (Tockner and Stanford 2002). Owing to the different capacity of movements of different organisms at different habitat ranges, their responses to landscape heterogeneity differ (Wiens 2002). Fish diversity, for example, may peak in highly connected habitats, whereas amphibian diversity tends to be highest in habitats with low connectivity (Tockner et al. 1998). Other groups attain maximum species richness between these two extremes.

The resulting pattern is a series of overlapping species diversity peaks along the connectivity gradient (Ward et al. 2002). Given the mutual interactions among species at differing levels in the food chain, ecosystem functioning reflects the range of habitats in any one setting and their connectivity.

7.20 Interlinking of Rivers in India: Issues and Concerns

The Indian plan of river interlinking has an international dimension because most of the Himalayan Rivers originated beyond the boundary of India and run through countries other than India, both upstream and downstream. Bangladesh located at the downstream drains out flows of the string of mighty Himalayan Rivers to the Bay of Bengal (Table 6.1).

7.20.1 Major Divisions of Indian Rivers

In the background of high-temporal and spatial variations in the availability of water resources in India, the vision to interlink rivers for the purpose of inter-basin water transfer, at a national scale, has been in the thoughts of well-meaning individuals and even engineers for more than a century (Prasad 2004). There are two main components of the proposal on interlinking of rivers in India (**ILR**), namely, the rivers of Himalayan origin and the rivers of Peninsular, India. The Himalayan rivers mostly carry water through the Brahmaputra and Ganga system and direct their flows westwards to southern Uttar Pradesh, Punjab, Haryana, Rajasthan, and adjoining areas and to some extent to the southwest Peninsular system in India.

The Peninsular Rivers component is concerned with the riverine networks of Mahanadi, Krishna, Godavari, Pennar and Cauvery, Parbati, Chambal, Tapi, Narmada, Pinjal, etc. Another option was surfaced in course of several discussions on **ILR** for the partial diversion of certain rivers flowing eastward into the Arabian Sea, in order to link them up with the rivers flowing into the Bay of Bengal, India.

7.20.2 Hydrological Implications

The implementation of the project component(s) will alter the hydrological settings of the river basins. The entire **ILR** project is designed based with aim at transferring water from "**areas of surplus to the deficit ones**." A seasonal picture on the average water surplus area leads to develop water deficit in the temporal and spatial scales as the requirements for water need to maintain some unique patterns in response to the ongoing demands for water to agriculture, industry, domestic, and other economic sectors (Prasad 2004). It is assumed that the flows of Ganges at downstream in and around Patna in the state of Bihar, India, will suffer from the severe water shortages due to river interlinking. Alteration of hydrological changes could also occur beyond the borders of India. In the upstream, Nepal would likely experience inundations from planned structures as they would be built near the border of India and Nepal. Further, if any structure(s) were built inside Nepal, hydrological changes would also likely occur in the river basins. In the downstream, due to the **ILR**, Bangladesh could experience hydrological droughts in the Ganges and Brahmaputra rivers.

7.20.3 Alternatives of the ILR

Are there any other alternatives to this costly project (**ILR**)? In order to justify the affirmative answer of this question, several alternatives have been suggested in some detail.

First, a huge amount of water is lost via evapotranspiration, distribution losses, seepage through unlined channels, and excess application in the crop fields. Canal irrigation water application efficiency in India is estimated at **35–40%**, which has remained at the same level for the last six decades. Water losses in the domestic and industrial uses are also believed to be **30–40%**. Therefore, investment of resources in increasing irrigation, domestic, and industrial water use efficiency can reduce demand for water and additional areas can be brought under irrigation with the water saved.

Second, enormous potential exists to increase the productivity of water in agriculture by raising crop productivity, combined with better water management practices. Deep soil chiseling prior to planting can dramatically improve water retention by the soil, while simultaneously reduce runoff and flooding. Crops grown in these conditions require less irrigation and generate much higher yields.

Third, the phasing out of subsidies in power and water can save resources by reducing their wasteful uses. Fourth, increasing the ability to efficiently use the available water for maximum benefit. Rainwater harvesting techniques in both urban and rural environment can substantially enhance the availability of water.

Some of these techniques are already in use and some of the ancient techniques have even been revived in many parts of India.

7.21 Politics and Reality on River Water Management

India has always attributed divinity to her rivers. The sacred rivers like the Saraswati, the Ganga, the Cauvery, and the Narmada have knit national mythology and traditions for centuries. Even today, pilgrims pay visit to Gaumukh, the origin of the rivers Ganga by undertaking arduous trekking although the glacier from where the river has been originated has receded **18** km away from the Ganga temple which was built around several thousand years ago at the initial location, named as the Gangotri in the gigantic mountain of Himalayas, India. Livelihoods, economy, religion, and culture of Indians are intertwined with the rivers from the time immemorial. India being home of over **130** cores of peoples is likely to become the most populous country of the world by the year **2050** (UN 2006). **The Interlinking of Rivers** (**ILR**) is proposed as one of the methods to meet increasing demand by making water available to the needy population.

Moreover, water is a very contentious political issue throughout India. It has explosive political ramifications which often snowball into violence and riots. The disputes pertaining to the sharing of Cauvery water in between the two southern states of India, Karnataka and Tamil Nadu are such example. In this instance, logical and reasonable management of water as a common resource became impossible due to regionalism, sentimentality, and emotions taking over the issue on hand. But, questions over the equitable sharing of water commonly arise in India, making water issues very controversial. Thus, the decision to decide on a technically feasible and politically benign **ILR** project could prove difficult. Excess rainfall during the monsoon season in some parts of the country often causes floods and natural disasters. The northeast and northern areas of India have been identified as regions in which experience floods on widespread scale (Nandargi & Dhar, 2006; 2011). The northeast region comprises the Brahmaputra basin and its tributaries and the north Indian region comprises the Ganga basin and its tributaries. These two rivers together generate about **60%** of total river flows of India. Irrigation using river water and groundwater has been the prime source of water to raise food grain production in India.

To meet this requirement, it would be necessary to increase irrigation potential to **160 Mha** for all crops by **2050**. The maximum irrigation potential of India has been assessed to be about **140 Mha** (Dehadrai 2003). The rivers of Brahmaputra and Ganga, India, especially with their northern tributaries, as well as rivers of southern India, mainly the Mahanadi and Godavari rivers along with some other west flowing rivers originating from the Western Ghats are found to be in surplus of water resources.

It is also presumed that regional imbalances of water availability could be reduced considerably on building of reservoirs on these rivers and developing connections with other parts of the country. A multitude of benefits are also expected to be derived after such developments which include irrigation, supply of water for domestic and industrial uses, generation of hydroelectric energy, development of navigational and recreational facilities, etc. The likely incidental benefits to realize irrigation potential include the mitigation of droughts, flood control, shipping activities, employment generation, fisheries, salinity control, pollution control, recreation facilities, infrastructural development, and socioeconomic development.

7.21.1 Adverse Impacts on Ecosystems

With the anticipated/modeled changes in hydrology, it may easily be inferred that the wetland ecosystems of Bangladesh will be severely affected as a consequence of implementation of the proposed **ILR**. Bangladesh has been known globally as a natural habitat for a large number of freshwater species including fish, mollusks, reptiles, riverine dolphins, plants, etc. a few of which are endemic species (Hussain and Acharya 1994). Early choking of smaller rivers would lead to fragmentation of freshwater habitat. With decreasing wetland areas and early recession of monsoon flows, many wetland species might find it difficult to maintain their life cycles. With landward movement of brackish water zone, spawning grounds for many species would shift, while increase in salinity along coastal rivers during critical dry season would limit naturally available spawning areas for freshwater fish species, which might be detrimental for fisheries diversity in Bangladesh. The effect of salinity ingress on the Sundarbans as a consequence of diversion of the Ganges flows has been well understood (Karim 2004).

Any further decrease in flow regime along the Gorai River during the critical dry period (March and April) might jeopardize the ecosystem health of the unique mangrove forest, the Sundarbans, India. For example, the vegetation succession processes in the forest are expected to change with increasing salinity (Karim 1994), which would result into gradual replacement of high-value timber species to low-value shrubs. With changing vegetation, one can only anticipate simultaneous changes occurring in biodiversity which are dependent on the forest species. The largest patch of productive mangrove forest, a pride possession of the humanity where the majestic Royal Bengal tiger inhabits would be deteriorated completely. The other interesting adverse effect would be on migratory species, which travel thousands of kilometers to avoid harsh winter in the northwest and spend few months enjoying favorable ecological on the vast shallow wetlands of the Bengal delta. Unfortunately, diversion of flows during September and October and early recession of water from the wetlands would severely affect temporary habitats of these migratory species.

7.21.2 Ecological and Economic Consequences of Interlinkages of Rivers (ILR)

In the backdrop of ever increasing population crowded together in a small landmass and having several other constrains such as poverty, malnutrition, illiteracy, etc., Bangladesh and major parts of eastern India have been struggling hard to offer minimum quality of life for the citizens because of lack of food self-sufficiency. In this pursuit, water-related hazards and disasters have always pushed the country backward and denied her strive towards development. On top, the unilateral withdrawal of water from the Ganges River by India wreaked havoc to natural environment of the Ganges dependent areas in Bangladesh, with huge economic and social adverse implications.

Any new attempt to jeopardize the region's water resources scenario, even if it is to serve people elsewhere in the region, would have devastating effects on geo-physical, biological, and human aspects of the most downstream country, Bangladesh. The proposed **ILR** would perhaps induce the greatest human tragedy in the history. It is urged upon the current leadership in India to carefully analyze the situation carefully and consider pragmatic win–win decisions. Let the laws of nature prevail over the laws of human beings that denies river water reaching its downstream and destroys potential for development.

7.22 Sustainable River Management: Demand of the Time

Modern river management needs to move towards an environmentally sustainable future, which means that solutions to water quality and water resource problems must in future seek technically self-sustaining options which are both economically efficient and enhance biodiversity (Department of Water Affairs and Forestry 1996). The outline above indicated that more "**natural**" river channels have much improved self-purification and resource storage capacity, which will need to be fully utilized by new management skills. Strategies to maximize habitat diversity will maximize biodiversity: evidence for this comes from a range of taxa in semi-natural rivers as well as invertebrates in restored rivers (Harper et al. 1995).

Nevertheless, it is important to maintain a holistic perspective, because maximum habitat diversity is not always synonymous with maximum channel naturalness. Harper et al. (1998) have shown that degraded lowland rivers can be recognized by reduced functional habitat diversity and that usually the cause of degradation can be deduced from the overdominant functional habitat present. For example, overwidening caused by excessive flood control engineering results in the dominance of the emergent macrophyte habitat, whereas overdeepening caused by impounding structures such as weirs and mills results in dominance by floating-leaved macrophytes. The extent of the habitat distortion can be compared both with **reference** sites from similar rivers and from a **theoretical** river of similar size created from geomorphological principles (meander pattern, riffle-pool sequence and, hence, substrate, flow velocity, distribution, and patterns of plant colonization).

7.23 Global Politics: Water, Human Need, and Conflicts

Given the undeniable importance of water to human affairs, the water issues have become political across the world highlighting it as scarcely surprising. The hard truth behind this, is the recognition of water as the first limiting resource for survivility of human beings. However, a sizable part of the world providing shelter of more than two (**2**) billion people is considered as water scarce area (Oki and Kanae 2006) and around one billion of peoples of the world are deprived of getting safe drinking water (Pimentel et al. 2004). Majority of cities all over the globe have been developed nearer to rivers, lakes, and other water bodies which serve not only as sources of water for direct human consumption but also as primary transportation avenues. Such overdependence of human society on water has appeared to be the right answer why, politics and water are deeply intertwined, particularly in arid regions.

Communities' conflicts over water have occurred throughout recorded history, mostly with the human community who appropriate water from far away from their habitations and therefore compelled to experience subsidization of water use to expedite developmental process (Gleick 2003). Political conflicts over water from the transboundary rivers of many countries were seen which include India–Pakistan, Israel–Jordan, Mexico–the USA, etc. during last one century. When water is a more limited commodity, its market value swells even more so as the economic values associated with ecosystem goods and services provided by water are increasingly recognized. The US Clean Water Act, the European Union's Water Framework Directive, India's system of Water Quality Standards, and the Law of the People's Republic of China on Prevention and Control of Water Pollution can be cited as examples to show the sincere efforts and attempts of different governments of the world to protect the quality of water and also to ensure the equitable sharing of useable water. This objective can be achieved by developing sound scientific understanding of the modes of functioning of aquatic ecosystems in view of ongoing human intervention of aquatic systems.

7.24 Conservation and Sustainability

7.24.1 Land and Water Conservation: Complimentary Effect of Each Other

7.24.1.1 Importance of Soil Conservation in the Context of River Basin Realities

Developing countries, like India being endowed with the problems of poverty and ever increasing population, should adopt integrated approach in the sustainable management of their natural resources of land and water, which constitute their basic life-support systems. As both of these resources are interlinked and interdependent, soil being an irreplaceable and nonrenewable resource requires proper soil and land management which automatically results in the conservation of a great deal of water. It should be a good strategy if special attention is paid on the neglect and sufferings of soil conservation in the past.

The afforestation of denuded watersheds, wastelands, river basins, and even on the flood plains, creation of adequate drainage facilities in canal-irrigated areas and the over use of ground water for irrigation, utilization of water for industries and hydroelectric power generation, development for fisheries and other recreation avenues, etc. should be integrated to ensure all river basin development programs.

7.24.1.2 Conservation and Eco-Management in the Past: Indian Perspective

A consideration of the concrete problems which have emerged in the field of land and water management in India would yield valuable insights into their relevance to developmental goals as well as the possible methods of solving them. Such an approach would also bring out the close interconnection between the management of land resources on the one hand and of water resources on the other, leading to develop the demand for undertaking an integrated approach towards management of both. In order to meet the need of increasing populations, the best possible use of the country's life-support system land and water resources should be the top most priority.

7.24.1.3 Priority to Land Resources

It is well to remember that while water is a replenishable resource, the soil is, for all purposes a nonrenewable and irreplaceable resource and therefore deserves greater care and attention than water. It accordingly makes sense to consider the problems of land management first and only thereafter those of water management. The problem of land management in India is truly formidable in size and scope. Around one-third of lands in India are almost completely unproductive, another one-third is partially productive, and it is only the remaining one-third which is in good health (Vohra 1973, 1980). It should be quite obvious, even to a superficial observer that there is no earthly chance of eradicating poverty and surviving as a self-respecting nation so long as such a state of affairs persists.

7.24.1.4 Threats Due to Deforestation

The most serious threat to the soil is posed by deforestation, denudation, and soil erosion. It is impossible to calculate the damage caused to the economy by these threats. Apart from the progressive loss of productivity which occurs on eroding soils – whether productivity of trees or grasses or crops, according to the use to which the land is put – the displacement of the top soil also causes the premature siltation of costly and often irreplaceable reservoirs which represent valuable potential for irrigation, for flood control, and for hydroelectric generation.

Again, displaced soil raises the beds of rivers, thus reducing their water carrying capacity and causing floods. Yet again, the excessive runoff of rain water along denuded slopes reduces its percolation into soil and subsoil strata and results in the loss to the sea, often after causing floods, of a resource which would otherwise have been available for round-the-year use as groundwater. Floods and droughts are thus two sides of the same coin of poor land management and conservation of the soil automatically results in the conservation of a great deal of water also. These simple ecological and hydrological realities of the country should be given priority in the river basin restoration and conservation processes keeping aside the big investment in the large river valley and also irrigation projects.

7.24.1.5 Canal Irrigation: A Mixed Blessing

Waterlogging and salinization have appeared to constitute the second major threat to the soil, and the lands affected are for the most part situated in canal-irrigated areas and have suffered basically because of the absence of adequate drainage. The situation calls for provision, as a matter of the highest priority, of adequate water distribution as well as drainage systems in all canal-irrigated areas, as prevention is always better than cure. However, even this threat is not yet viewed seriously enough, with the result that command area development and drainage works languish for want of resources even as huge amounts are spent on new irrigation works. The conservation and optimal management of land resources does not enter into their calculations to any large extent. The mistake of course lies in treating canal irrigation as if it was an end in itself, instead of only a means to greater productivity of the soil.

7.24.1.6 Options for Improvements in Land Productivity

In the utterly lopsided resource management situation, the productivity of the soil can be improved under different land-use conditions, in order to utilize limited resources to the best advantage of the community by testing with various options. Canal-irrigated areas, which account for around **50%** of the total net irrigated area in India offer the greatest scope for a quick increase in production. Very high priority, therefore needs to be given to the completion of command area and drainage works in such lands even if this involves the slowing down or even postponement of new irrigation projects.

Putting of existing irrigation potential to optimal use and to save precious land from damage by waterlogging and salinization than to create additional capacity is bound to remain underutilized as well as to pose a grave hazard to the soil. This is so because of the intrinsic nature of this resource, which lends itself beautifully to development by individual farmers at little expense and in record time. However, the very attractiveness of this resource creates the danger of its over exploitation. At the same time, however, the use of groundwater, wherever it is available in plenty must be encouraged by all possible means such as the consolidation of holdings, the electrification of pumpsets, the provision of loans, and the extension of competent technical advice to the farmer. However, the replenishment of groundwater must be maximized by taking comprehensive afforestation along with soil and water conservation measures in the watersheds.

7.24.1.7 Advantages of Groundwater Utilization

In considering a rational strategy for the extension of irrigation in the interests of increased production, due importance must be given to the many unique natural advantages which groundwater enjoys over surface water as a source of irrigation. These advantages flow from the fact that no expenditure has to be incurred on either the storage or the conveyance of ground water, no land needs to be acquired for either the reservoir or canal systems, and no seepage losses. Groundwater is also not susceptible to evaporation losses either during storage or transit.

Problems of water distribution and drainage, which cause waterlogging and salinization in canal-irrigated areas, are also almost nonexistent in areas served by groundwater because there is no seepage from canals. It therefore stands to reason that wherever it is felt necessary to supply water to non-irrigated lands, the possibility of using groundwater should be explored to the full before turning to the surface water option.

7.24.1.8 Conservation Measures in Rainfed Areas

Most of the soils in lands suffer from water scarcity, deforestation, erosion pressure, least moisture retention ability, etc. In order to ensure the development of vegetation and also agriculture, such lands must be provided with irrigation facilities to the maximum extent possible. Rainfed lands which are subject to wind erosion must be protected by wind brakes and shelter belts. However, while considering the optimum utilization of rainfed agricultural lands, due account should be taken of the fact that a significant proportion of such lands are intrinsically unsuitable for sustained cultivation on account of either the steepness of their slopes or the shallowness of their soils or both.

7.24.1.9 Development of Management Policy: Emphasis on Peoples Participation

However, the paucity of funds has appeared to the major constrains in undertaking requisite scale of management practices to save the land from further degradation and to put it to optimal use, it is need of the hour to carry out far-reaching policy changes to reorient the thinking of departmental agencies which have got used to working in watertight compartments with very limited objectives and to build entire new cadres capable of planning and executing works on the required scale in a timebound manner.

7.24.1.9.1 Prospects of the Involvement of Participation of Local Communities

One of the serious considerations is whether one should think in terms of employing only departmental agencies for executing afforestation, land leveling, drainage, and other land improvement works. Recent past activities towards management and conservation of natural resources, departmental agencies have not only proved to be often inefficient and very much expensive without showing the courage and interest in taking up huge new responsibilities with any sense of confidence.

The new jobs are in fact so enormous in size and scope that they can hardly be achieved without the active cooperation and indeed the participation of local communities who have a direct stake in the better utilization of the resources on which they depend for their living. Fortunately, a great deal of the works involved whether afforestation or land leveling or bounding or the construction of field channels and drains are fairly non-technical in nature and can be easily performed, with a little guidance and training, by the local peoples themselves, involving a fraction of the cost incurred by departmental agencies.

The participation of the people is also, of course, inescapably necessary from the point of view of ensuring the proper maintenance and protection of the new works and plantations. The Government agencies and departments concerned with various land management programs will, therefore, have to acquire an entirely new ethos in order to measure up to the task ahead giving up their present attitudes of distrust, distance, and naughtiness towards the people and developing the spirit to learn to work with and for them with the trust of cooperation, mutual confidence, and camaraderie. Such a change will in turn be possible only if the present bias for overcentralization of authority is given up and field organizations are given much greater powers and flexibility than they enjoy today, so that these in turn may be shared by them with local communities in the interests of quick and cost-effective implementation.

All this, however, is easier to comment than to perform. It is indeed only after a strong political will has come into being that it will be possible to carry out the far-reaching administrative and organizational reforms required to put matters right. A joint venture involving the administrators, local peoples, politicians, researchers, and planners can take up the matter for tackling and controlling of different interconnected environmental problems such as water pollution, promotion of navigation, the generation of hydroelectric power, and the planning of urban expansion on correct lines.

7.25 Sustainability of Conservation: Ecological Basis

The concept of sustainability appears frequently in contemporary thought as the cornerstone of the ecological research agenda for the time to come (Lubchenco et al. 1991). The definition of sustainability depends on the context in which it is used (Brown 1987) because the implications of the concept vary depending on its relevance to the ecology, or economy or society (Shearman 1990). A "**sustainable biosphere**" can be envisioned in which the diversity of life on earth persists, where the biosphere supports the current generation of humans while leaving an equitable share of resources for future generations. This concept of intergenerational equity is the backbone of sustainability (Table 7.1).

Sustainable resource management means far more than continued commodity production at some rate. It also addresses the social and environmental issues associated with harvesting the resource. In its consideration of ecological research priorities, the Ecological Society of America (**ESA**) adopted a specific definition of sustainability (Lubchenco et al. 1991) as "**management practices that will not degrade the exploited system or any adjacent systems**" and recognized that "**consumption standards that are within the bounds of ecological possibility and to which all can aspire**" are necessary to its realization. Based on the recent history of development projects, "**sustainable development**" sounds like an oxymoron, yet it is a political reality today.

The concept of sustainability as a solution to problems of exploitation is embraced not because of its proven record, but because it offers a viable alternative to uncontrolled exploitation. The political and economic reality is that powerful interests stand to profit in the short term from the harvest of natural resources. Sustainable development is usually discussed in the context of aid to developing countries; however, industrialized societies are in need of developing sustainable approaches to resource extraction and use. Although sustainable development is necessary, it is not sufficient without sustainable redevelopment in the industrialized world. Such redevelopment includes altered practices of product production and consumption that emphasize recycling and increased conservation of water, energy, and resources. The critical question is whether sustainable resource use can be achieved in a free market-based capitalist economic setting.

As has been pointed out by many authors (Ludwig et al. 1993), failure to achieve sustainable resource use is a consequence of two realities:

1. Power is generated by the wealth resulting from unfettered resource exploitation
2. Management of resources is complex, not amenable to study by reductionist methods, and natural variability makes early detection of management failures difficult

The task, then, is to confront these realities and seek an alternative path. Addressing the first reality requires a shift in economic analysis. It is unlikely that a sustainable biosphere will be achieved without a change in the way our natural resources are valued. What is required is an economic perspective on resource exploitation that recognizes the value of components of the environment other than the commodity being exploited. New approaches to economics are being developed and debated (Costanza and Herman 1992). The importance of progress in linking economic and ecological science was recognized in **ESA's Sustainable Biosphere Initiative** (**SBI**), which noted an urgent need of two approaches:

1. To forge new theory with an emphasis in explicitly incorporating both economic and ecological principles.
2. To undertake in-depth research and analysis of research information of the relevant economics of exploitation and conservation (Lubchenco et al. 1991). All these have triggered further analysis, discussions, and debates of the **SBI** (Levin 1992).

Confronting the second reality will require a change in the way ecological science is done, specifically taking a broader systems perspective of the problem and incorporating the human dimension of ecological issues. That is precisely what is invoked in the **SBI** document. It is presented as a "**call to arms**" for ecologists (Mooney and Levin 1991), and its implementation has reflected the importance placed on changes in the way ecologists do and view their research (Levin 1992). Other groups opine that for developing sustainable agriculture (NRC 1989, 1991a) and forestry (NRC 2001). The need for a change in the traditional approach to problem-solving in agriculture in developing countries is imperative including crossing traditional disciplinary boundaries, incorporation of indigenous knowledge, and involving the farmer as a means of setting a practical context for research (NRC 1991a). It can be argued that past failures in developing sustainable resource use result from researchers and managers not taking a sufficiently broad systems perspective. It is not adequate for an ecologist to work in isolation to devise a sustainable natural resource management. Resource managers generally work together with stipulated regulations. Ecological research is necessary but not sufficient. A better understanding of global ecology will be to no avail without the political will to implement the changes dictated by that understanding.

Ecological research has a long history of significant contributions in detection of change in areas such as lake eutrophication, acid precipitation, and consequences of exotic species introductions. Continued ecological research is essential for monitoring and understanding the causes of environmental change and in devising models of sustainable exploitation that operate in an inherently variable world. Management decisions also offer opportunities for the use of ecological research to help guide and evaluate their effectiveness. Ecological research will be essential to design sustainable systems that meet human needs in the range of environmental conditions around the globe. Designing sustainable systems for agriculture, forestry, fisheries, or waste purification requires local ecological knowledge.

It is unlikely that sustainable methods will be globally applicable; developing sustainable systems will require adapting to the local situation, which relies upon understanding ecological, social, and cultural conditions. Ecological research is required for disciplines essential for a sustainable society such as ecological engineering and restoration ecology. Ecological engineering uses ecological principles to design systems that serve human needs and are fueled by solar rather than fossil fuel energy (Mitch and Jorgensen 1989). An increased reliance on incoming solar energy would seem to be a key ingredient in achieving sustainability. Current examples of such systems include wetlands designed to treat sewage, industrial wastes, and acid mine drainage (Mitch and Jorgensen 1989; Yan et al. 1993).

Designing systems for the future is limited only by ecological knowledge and creativity and the laws of thermodynamics. There is also need for ecological research to guide efforts aimed at undoing the damage done by our current unsustainable practices. The field of restoration ecology relies on continuing ecological research to guide restoration efforts. Environmental scientists have been criticized for being unable to agree among themselves on the nature of problems or on solutions to problems (Ludwig et al. 1993). Ecologists have produced the **Sustainable Biosphere Initiative** (**SBI**) (Lubchenco et al. 1991), a consensus document describing research priorities for achieving a sustainable biosphere. However, based on the research outcomes of **SBI** results, ecologists have got new avenues with their new innovative unlike their existing ones which have sounded a call to the ecological community, providing them with three undermentioned areas of high-priority research:

1. Eco-assessment of environmental health
2. Undertaking holistic approach in designing conservation strategies
3. Execution and implementation of designed goals involving local peoples

References

Angermeier, P.L., and J.R. Karr. 1994. Biological integrity versus biological diversity as policy directives. *Bio Science* 44 (10): 690–697.

Arnell, N. 1989. The influence of human activities on hydrological characteristics: An introduction. In *Human influences on hydrological behaviour: An international literature survey*, ed. N. Arnell, 1–18. Paris: UNESCO.

Axelrod, L.J. 1994. Balancing personal needs with environmental preservation: Identifying the values that guide decisions in ecological dilemmas. *Journal of Social Issues* 5: 85–104.

Baron, J.S., N.L. Poff, P.L. Angermeier, C.N. Dahm, P.H. Gleick, N.G. Hairston, R.B. Jackson, C.A. Johnston, B.D. Richter, and A.D. Steinman. 2002. Meeting ecological and societal needs for freshwater. *Ecological Applications* 12: 1247–1260.

Bingham, G. 1986. *Resolving environmental disputes: a decade of experience*. Washington, DC: Conservation Foundation.

Botkin, D.B. 1990. *Discordant harmonies: A new ecology for the 21st century*. New York: Oxford University Press.

Bottrall, A. 1992. Institutional aspects of watershed management. In *Overseas development agency, priorities for water resources allocation and management*, 81–90. London: ODA.

Boulding, K.F. 1963. *Conflict and defence, a general theory*. New York: Harper and Row.

Bourne, L.S. 1976. Urban structure and land use decisions. *Annals of the Association of American Geographers* 66 (4): 531–535.

Brookes, A. 1988. *Channelized rivers: Perspectives for environmental management*. Chichester: Wiley.

———. 1992. Recovery and restoration of some engineered British river channels. In *River conservation and management*, ed. P.J. Boon, P. Calow, and G.E. Petts, 337–352. Chichester: Wiley.

———. 1995a. Challenges and objectives for geomorphology in UK river management. *Earth Surface Processes and Landforms* 20: 593–610.

———. 1995b. River channel restoration: Theory and practice. In *Changing river channels*, ed. A. Gurnell and G.E. Petts, 369–388. Chichester: Wiley.

Brookes, A., and K.J. Gregory. 1988. Channelization, river engineering and geomorphology. In *Geomorphology in environmental planning*, ed. J.M. Hooke, 145–167. Chichester: Wiley.

Brookes, A., and F.F. Shields. 1996. *River channel restoration: Guiding principles for sustainable projects*. Chichester: Wiley.

Brown, A.G. 1987. Long-term sediment storage in the Severn and Wye catchments. In *Palaeohydrology in practice*, ed. K.J. Gregory, J. Lewin, and J.B. Thomas. Chichester: Wiley.

Costanza, R., and E.D. Herman. 1992. Natural capital and sustainable development. *Conservation Biology* 6 (1): 37–46.

Crandall, K.A., O.R.P. Bininda-Emonds, G.M. Mace, and R.K. Wayne. 2000. Considering evolutionary process in conservation biology. *Trends in Ecology and Evolution* 15 (7): 290–295.

Dehadrai, P.V. 2003. Irrigation in India. F.A.O. *Fish Technnical paper* 430: 59–69.

Department of Water Affairs and Forestry. 1996. *Water law principles*. Discussion document, Pretoria.

Falkenmark, M. 1981. Integrated view of land and water. The new cornerstone in environmental planning. Geografiscka Annaler. Series A. *Physical Geography* 63 (3/4): 261–271.

Ferguson, R.I. 1981. Channel form and channel changes. In *British rivers*, ed. J. Lewin, 90–125. London: Allen and Unwin.

Gadgil, M., and Ramachandra Guha. 1994. Ecological conflicts and the environmental movement in India. *Development and Change* 25: 101–136.

Gleick, P.H. 1998. *The world's water 1998–1999: The biennial report on freshwater resources*. Washington, DC: Island Press.

———. 2002. Water management: Soft water paths. *Nature* 418 (6896): 373–373.

———. 2003. Global freshwater resources: Soft-path solutions for the 21st century. *Science* 302: 1524–1528.

Gould, S.J. 1995. *Dinosaur in a haystack: Reflections in natural history*. New York: Harmony Books.

Harper, D.E. 1988. Improving the accuracy of the universal soil loss equation in Thailand. In *Land conservation for future generations*, ed. S. Runwanich, 531–540. Bangkok: Department of Land Development.

Harper, D.M., and A.J.D. Ferguson. 1995. *The ecological basis for river management*. Chichester: Wiley.

Harper, D.M., M. Ebrahimnezhad, and F. Climent. 1998. River restoration: Setting the goals and measuring the success. *Aquatic Conservation: Marine and Freshwater Ecosystems* 8: 5–16.

Harper, D., C. Smith, P. Barham, and R. Howell. 1995. The ecological basis for the management of the natural river environment. In *The ecological. Basis for river management*, ed. D.M. Harper and A.J.D. Ferguson, 219–238. Chichester: Wiley.

Harper, D.M., J.L. Kemp, B. Vogel, and M.D. Newson. 2000. Towards the assessment of 'ecological integrity' in running waters of the United Kingdom. *Hydrobiologia* 422 (423): 133–142.

Hobbs, R.J., and J.A. Harris. 2001. Restoration ecology: Repairing the Earth's ecosystems in the new millennium. *Restoration Ecology* 9: 239–246.

Hobbs, R.J., and L.F. Huenneke. 1992. Disturbance, diversity, and invasion – Implications for conservations. *Conservation Biology* 6: 324–337.

Hobbs, R.J., and D.A. Norton. 1996. Towards a conceptual framework for restoration ecology. *Restoration Ecology* 4 (93–1): 10.

Hobbs, R.J., S. Arico, J. Aronson, J.S. Baron, P. Bridgewater, V.A. Cramer, P.R. Epstein, et al. 2006. Novel ecosystems: Theoretical and management aspects of the new ecological world order. *Global Ecology and Biogeography* 15: 1–7.

Hobbs, R.J., E. Higgs, and J.A. Harris. 2009. Novel ecosystems: Implications for conservation and restoration. *Trends in Ecology and Evolution* 24: 599–605.

Holling, C.S. 1973. Resilience and stability of ecological systems. *Annual Review of Ecology and Systematics* 4: 1–23.

Howitt, R. 1992. *Industrialisation, impact assessment and empowerment. Indigenous peoples and development issues*, Auckland, New Zealand.

Hussain, Z., and G. Acharya, eds. 1994. *Mangrove of the Sundarbans (volume-II) Bangladesh*. Thailand: IUCN-Bangkok, Dyna Print.

IUCN (International Union for the Conservation of Nature). 2000. *Vision for water and nature: A world strategy for conservation and sustainable management of water resources in the 21st century*. Gland/Cambridge: International Union for the Conservation of Nature.

Junk, W.J., P.B. Bayley, and R.E. Sparks. 1989. The flood pulse concept in river-floodplain systems. In *Proceedings of the international large river symposium, Canadian special publication of fisheries and aquatic sciences*, ed. D.P. Dodge, vol. 106, 110–127.

Karim, A. 2004. Implications on ecosystems in Bangladesh. In *The Ganges water diversion: Environmental effects and implications*, ed. M.M.Q. Mirza, 125–161. Dordrecht: Kluwer Academic Publishers.

Karim, K., M.E. Gubbels, and I.C. Goulter. 1995. Review of determination of instream flow requirements with special reference to Australia. *Water Resources Bulletin* 31: 1063–1077.

Levin, S.A. 1992. The problem of pattern and scale in ecology. *Ecology* 73: 1943–1967.

Levins, R. 1969. Some demographic and genetic consequences of environmental heterogeneity for biological control. *Bulletin of the Entomological Society of America* 15: 237–240.

Lubchenco, J., Annette M. Olson, Linda B. Brubaker, Stephen R. Carpenter, Marjorie M. Holland, Stephen P. Hubbell, Simon A. Levin, James A. MacMahan, Pamela A. Matson, Jerry M. Melillo, Harold A. Mooney, Charles H. Peterson, H. Ronald Pullian, A. Leslie, J. Real Philip, Regal, and Paul G. Risser. The sustainable bioshere initiative: An ecological research agenda: A report from the Ecological Society of America. *Ecology* 72 (2): 371–412. (Ecological Society of America).

Ludwig, J.P., Heidi J. Auman, Kurita Hiroko, M.E. Ludwig, L.M. Campbell, J.P. Giesy, D.E. Tilltt, P. Jones, N. Yamashita, S. Tanabe, and R. Tatsukawa. 1993. Caspian tern reproduction in the Saginaw Bay ecosystem following a 100-year flood event. *Journal of Great Lakes Research* 19 (1): 96–108.

Mascarenhas, O., and P.G. Veit. 1994. *Indigenous knowledge in resource management: Irrigation in Msanzi, Tanzania*. Washington, DC: World Resources Institute.

Mitsch, W.J., and J.G. Gosselink. 1993. *Wetlands*. 2nd ed. New York: Van Nostrand Reinhold.

Mittermeier, R.A., I. Tattersall, W.R. Konstant, D.M. Meyers, and R.B. Mast (1994, 1998). *Lemurs of Madagascar*. Washington, DC: Conservation International.

Mittermeier, R.A., N. Myers, and C.G. Mittermeier. 1999. *Hot spots -Earths biologically richest and most endangered terrestrial ecoregions*. New York: CEMEX, Conservation International.

Mooney, H.A. 1991. Biological response to climate change: An agenda for research. *Ecological Applications* 1: 112–117.

Moore, D.J., ed. 1982. *Catchment management for optimum use of land and water resources: Documents from an ESCAP seminar, Part 2: New Zealand contributions*, 394 Bibliography Water and Soil Miscellaneous Publication 45. Wellington: National Water and Soil Conservation Authority.

Moritz, M. 2006. The politics of permanent conflict: Farmer-herder conflicts in northern Cameroon. *Canadian Journal of African Studies* 40 (1): 101–126.

Naiman, R.J. 1997. Large animals and system-level characteristics in river corridors. *Bioscience* 47: 521–529.

Naiman, R.J., and H. Decamps. 1990. *The ecology and management of aquaticterrestrial ecotones*. Carnforth: Parthenon.

Namoi, C.M.A. 2013. *Namoi catchment action plan 2010–2020*. Supplementary document 1, the first step-preliminary resilience assessment of the Namoi Catchment. http://bit.ly/1927IHq. Accessed 10 Nov 2015.

Nandargi, S., and O.N. Dhar. 2006. Tropical disturbances and Indian monsoon rainfall. *Journal of Applied Hydrology. Special issue* 19 (3): 1–7.

———. 2011. Extreme rainfall events over the Himalayas between 1871 and 2007. *Hydrological Sciences Journal* 56 (6): 930–945.

Noss, R.F. 1990. Indicators for monitoring biodiversity: A hierarchical approach. *Conservation Biology* 4: 355–364.

NRC. 2001. *Compensating for wetland losses under the clean water act*. Washington, DC: National Academy Press.

Oki, T., and S. Kanae. 2006. Global hydrological cycles and world water resources. *Science* 313 (5790): 1068–1072.

Pahl-Wostl, C., M. Craps, A. Dewulf, E. Mostert, D. Tabara, and T. Taillieu. 2007. Social learning and water resources management. *Ecology and Society* 12 (2): 5. http://www.ecologyandsociety.org/vol12/iss2/art5/.

Petts, G.E., and C. Amoros. 1996. *Fluvial hydrosystems*. London: Chapman & Hall.

Pimentel, D., B. Berger, D. Filiberto, et al. 2004. Water resources: Agricultural and environmental issues. *Bioscience* 54: 909–918.

Postel, S.L., and S.R. Carpenter. 1997. Fresh water ecosystem services. In *Nature's services*, ed. G. Daily, 195–214. Washington, DC: Island Press.

Prasad, T. 2004. Interlinking of rivers for inter-basin transfer. *Economic and Political Weekly* 39 (12): 1220–1226.

Pringle, C.M., M.C. Freeman, and B.J. Freeman. 2000. Regional effects of hydrologic alterations on riverine macrobiota in the New World: Tropical-temperate comparisons. *Bioscience* 50: 807–823.

Ricardo, D. 1926. *Principles of political economy and taxation*. London: Everyman.

Richter, B.D., and G.A. Thomas. 2007. Restoring environmental flows by modifying dam operations. *Ecology and Society* 12 (1): 12. http://ecologyandsociety.org/vol12/iss1/art12. Accessed 10/24/2007.

Richter, B.D., J.V. Baumgartner, J. Powell, and D.P. Braun. 1996. A method for assessing hydrologic alteration within ecosystems. *Conservation Biology* 10 (4): 1163–1174.

Richter, B.D., J.V. Baumgartner, R. Wigington, and D.P. Braun. 1997. How much water does a river need? *Freshwater Biology* 37: 231–249.

Rogers, K.H., and R. Bestbier. 1997. *Development of protocol for the definition of the desired state of riverine systems in South Africa*. Department of Environmental Affairs and Tourisms, Pretoria, South Africa. Available online at http://www.ngo.grida.no/soesa/nsoer/resource/wetland/abstract_protocol.htm

Rouget, M., D.M. Richardson, R.M. Cowling, and J.W. Lloyd. 2003. Current patterns of habitat transformation and future threats to biodiversity in terrestrial ecosystems of the Cape Floristic Region. *Biological Conservation* 112: 63–85.

Rouget, M., R.M. Cowling, A. Lombard, and A. Knight. 2006. Designing large-scale conservation corridors for patterns and process. 20 (2): 549–561.

Rogers, K.H. 2003. Adopting a heterogeneity paradigm; implications for management of protected savannas. In *The Kruger experience: Ecology and management of Savanna heterogeneity*, ed. J.T. Du Toit, K.H. Rogers, and H.C. Biggs, 41–58. Washington, DC: Island Press.

Scheffer, M., S.R. Carpenter, J. Foley, C. Folke, and B.H. Walker. 2001. Catastrophic shifts in ecosystems. *Nature* 413: 591–596.

Sendzimir, J., P. Magnuszewski, Z. Flachner, P. Balogh, G. Molnar, A. Sarvari, and Z. Nagy. 2008. Assessing the resilience of a river management regime: Informal learning in a shadow network in the Tisza River Basin. *Ecology and Society* 13 (1): 11.

Shearman, R. 1990. The meaning and ethics of sustainability. *Environmental Management* 14 (1): 1–8.

Simpson, J.C., and R.H. Norris. 2000. Biological assessment of river quality: Development of

Simpson, R.D., and R. Sedjo. 2004. Golden rule of economics yet to strike prospectors. *Nature* 430: 723.

Soulé, M., J.A. Estes, et al. 2003. *Ecological effectiveness: Conservation goals for Souri River and effects on fish and wildlife*, Aquatic Series No. 11. Jefferson City: Missouri Department of Conservation.

Sparks, R.E. 1995. Need for ecosystem management of large rivers and their flood-plains. *Bioscience* 45: 168–182.

Stein, J.L., J.A. Stein, and H.A. Nix. 2002. Spatial analysis of anthropogenic river disturbance at regional and continental scales: Identifying the wild rivers of Australia. *Landscape and Urban Planning* 60: 1–25.

Stoeckel, J.A., D.W. Schneider, L.A. Soeken, K.D. Blodgett, and R.E. Sparks. 1997. Larval dynamics of a riverine metapopulation: Implications for zebra mussel recruitment, dispersal, and control in a large-river system. *Journal of the North American Benthological Society* 16: 586–601.

Tagil, S., ed. 1977. *Studying boundary conflicts. A theoretical framework*. Lund: Studies in International History.

Teclaff, L. 1967. *The river basin in history and law*. The Hague: Martinus Nijhoff.

Tockner, K., and J.A. Stanford. 2002. Riverine floodplains: Present state and future trends. *Environmental Conservation* 29: 308–330.

Tockner, K., F. Schiemer, and J.V. Ward. 1998. Conservation by restoration: The management concept for a riverfloodplain system on the Danube River in Austria. *Aquatic Conservation: Marine and Freshwater Ecosystems* 8: 71–86.

UNDP. 1975. *Proceedings of the interregional seminar on water resources administration*. DP/UN INT-70- 371, New Delhi.

Vannote, R.L., G.W. Minshall, K.W. Cummi, J. Sedell, and C.E. Cushing. 1980. The river continuum concept. *Canadian Journal Fisheries and Aquatic Sciences* 37: 130–137.

Veit, P.G., A. Mascarenhas, and O. Ampadu-Agyei. 1995. *Lessons from the ground up: African development that works*. Washington, DC: World Resources Institute.

Vohra, B.B. 1973. A charter for the land. *Economic and Political Weekly* VII (13): A2–A16. (31, March).

———. 1980. *A land and water policy for India*, Sarder Patel memorial lectures. New Delhi: Publication Division.

Ward, J.V., K. Tockner, D.B. Arscott, and C. Claret. 2002. Riverine landscape diversity. *Freshwater Biology* 47: 57–539.

Wehr, J.D., and Jean-Pierre Descy. 1998. Use of phytoplankton in large river management. *Journal of Physiology* 34: 741–749.

Wehr, J.D., and J.H. Throp. 1997. Impacts of navigation dams, tributaries, and littoral zones on phytoplankton communities in the Ohio River. *Canadian Journal of Fisheries and Aquatic Sciences* 54: 378–395.

Wiens, J.A. 2002. Riverine landscapes: Taking landscape ecology into the water. *Freshwater Biology* 47: 501–515.

Yan, Y.Z., H. Wang, R. Zhu, L. Chu, and Y.F. Chen. 2013. Influences of low-head dams on the fish assemblages in the headwater streams of the Qingyi watershed, China. *Environmental Biology of Fish* 96: 495–506.

Zazueta, A. 1995. *Policy hits the ground: Participation and equity in environmental policy-making*. Washington, DC: World Resources Institute.

Chapter 8
Eco-restoration of Rivers

Abstract Rivers, the fluvial landscape enabled both ancient and modern societies to develop and flourish in the proximity of rivers which fundamentally shape the present earth with all its living and nonliving entities including human being. However, humans have spatially and temporally altered rivers since time immortal because of intensive use of the rivers for navigation, flood control, abstraction of water for drinking and agriculture, urbanization coupled with industrialization, disposal of wastes including sewage, thermal effluents, both nontoxic and toxic chemicals alongside river bed mining, dredging, and construction of dams, barrages, etc.

Large river systems all over the world have been extensively dammed for hydroelectric power, recreation, and flood control and to divert water to support agriculture which have caused not only massive alteration of habitats but led to the loss of fisheries and the ecological balance in the river ecosystem. The severity and extent of human-mediated eco-degradation and disturbances of the aquatic ecosystems have prompted to undertake corrective interventions, in order to restore or rehabilitate lost and/or damaged ecosystem functions. Recent interest in river restoration reflects a significant change in river managerial regimes.

It also reflects a wider fascination with "**ecological restoration**" in the scientific and technical literature and in public debates about approaches to environmental management. The concept of making or inducing positive changes in ecosystems is controversial, both in theory and practice. Restoration programs and relevant research projects are characterized by being one of the major goals, i.e., returning of the old so-called pristine normal environmental condition from its present degraded state of affairs. But such mission often contributes to develop sometimes conflicts with a number of other different purposes. Restoration projects involve surface and groundwater flow and quality regimes and focus on the impacts of those regimes on natural aquatic and terrestrial ecosystems as well as human economic and social "**ecosystems**." Processes that control river ecosystems are hierarchically nested, both spatially and temporally.

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Long-term geologic, tectonic, and climatic processes create the landscape template that controls the structure of river networks and valley forms, which are generally immutable over human time frames. The landscape template sets limits on the types of habitats and process rates that are expressed in river reaches, but watershed- and reach-scale processes control conditions at any point in time.

Runoff and erosion processes control stream flow and sediment supply, while nutrient supply processes control primary productivity at the base of the food web. Reach-scale processes, including routing of sediment and water, river–floodplain interactions, riparian processes, and instream biological processes control ecosystem conditions at the reach level. Human impacts to these processes include both indirect and direct effects on habitats and ecological systems. Indirect effects are those that affect processes away from the stream, such as land-use effects on erosion or runoff processes that ultimately affect stream flow or sediment supply, or riparian vegetation impacts that affect stream temperature or wood and nutrient supply. Direct manipulations of river channels and biota include impacts such as dredging or channel control structures or directs effects on biota such as fishing, hatchery practices, and stocking of non-native species.

Successful river ecosystem restoration is rooted in a clear understanding of linkages between causes of habitat change and the resultant effects of habitat change on biota and ecosystem processes. These cause–effect linkages are the foundation of process-based restoration, which aims to restore watershed and river processes that drive ecosystem functions and features. Process-based restoration is guided by four fundamental principles, including identifying major reasons for the change of habitat and ecosystem, involving local perspectives toward restoration actions, harmonizing scale of restoration with the ongoing biological and physical and biological processes, and explicitly stating expected outcomes.

The purpose of these principles is to guide river restoration toward actions that require minimal maintenance and create a resilient river system that adapts to future perturbations such as climate change. These principles also help define the needs of watershed assessments, inform how restoration actions should be identified and prioritized, support development and design of restoration projects, and guide the development of monitoring plans that track success or failure of projects. The present chapter has elaborately discussed multidimensional aspects of the science of restoration starting from the basic concept to its applicability and problems of implementation to different success stories citing several case studies.

Keywords Restoration ecology · Fluvial landscape · Ecological balance · Social ecosystems · Runoff and erosion · Ecological restoration · Rehabilitation · Remediation · Reclamation · Re-creation · Ecological recovery · Bioremediations · Roles of Niche theory and ecotypes in eco-restoration · The hierarchical structure of watersheds and riverine ecosystems · Key steps and plannings in river restoration · Roles of biota in the river restoration process

8.1 Restoration Ecology: Emergence and Relevance of the Subject

Restoration ecology being a sub-discipline of ecology informs the **intentional activity that begins with an objective for all round regaining, recovery and returning of an ecodegraded ecosystem in respect of its ecological health, integrity and sustainability**. Like other broader fields of ecology, restoration ecology is an integrative discipline, having drawn important influences from fields as diverse as other applied sciences (Mitsch 1993), sociology (Geist and Galatowitsch 1999), landscape architecture (Fabos 2004), soil science (Bradshaw 1997), hydrology (Morris 1995), population ecology (Rosenzweig 1987), and landscape ecology (Van Diggelen 2006). This diversity of influences has led to many different approaches and goals for restoration projects. The strongest conceptual framework for most of restoration ecology relies on the research information pertaining to community and ecosystem ecology which takes into consideration of restoring of the structure and function of the ecosystems (Ehrenfeld and Toth 1997; Palmer et al. 1997; Young 2000; Falk et al. 2006).

Considering all, the prime focus of restoration ecology is to understand the underlying ecological processes for restoring either biodiversity, ecosystem functioning, or both.

8.2 River Restoration: Definition and Goals

8.2.1 Concept and Definition

As the field and concept of restoration ecology undergo lack of clarity concerning its meaning, goals, and objectives, it appears to be challenging to designate properly the very term river ecology. Since mid-1980s, the domain of river restoration has increasingly evolved with an objective to better address the needs of human societies' in respect of arresting and repairing the trend of eco-degradation with ecological damage of rivers (Cairns and Heckman 1996; Karr and Chu 1999; Cairns 2001; Brookes 1995b; Beechie et al. 1999, 2006, 2008, 2008a, 2009, 2010). The term restoration has been defined by the Society of Wetland Scientists (SWS 2000) as "actions taken in a ecologically degraded or altered natural wetland in order to re-establish of the ecological processes within the erstwhile wetland, including function, and linkages among biotic and abiotic components in such a way so that a persistent, and resilient system be developed and integrated to facilitate the targeted recovery processes."

The term restoration has also been defined by the Society for Ecological Restoration (SER 2002) as the "**process of promoting the recovery of a degraded, damaged, or destroyed ecosystem**." The definition of restoration given by the United States National Research Council (NRC 1999) as '**the return of an**

eco-degraded ecosystem to a close approximation of its condition prior to disturbance' which was further expanded by Cairns et al. 2001, who inclined on the main target of restoration as the '**returning of damaged ecosystems to an ecological state that is structurally and functionally very nearer to the pre -disturbance state**'.

8.2.2 Goals and Objectives of Eco-restoration

Like that of definitions, the goals and objectives of river restoration are not clear. Rolston (1988) expressed doubts on the possible return of the degraded ecosystem to its **natural** or **original** condition. Westra (1995) argued that the ongoing change and development in the restoration processes are mostly constrained by human interruptions during the past and also in the present.

Alternatively, other definitions proposed in the fields of restoration ecology explicitly focus on social, cultural, historical, political, aesthetic, and moral aspects. Sweeney (2000) stressed on the value-laden social and ethical perspectives toward the building of a "**restored**" ecosystem. A number of other field ecologists put forward their views on conservation and restoration of river ecosystem that put more emphasis on the involvement and direct participation of local and indigenous people who are intimately associated with the nearby riverine tracts for their cultural and physical subsistence, along with the considerations of underlying scientific principles adhering mainly to the knowledge of ecology (Gomez-Pompa 2009; Berkes et al. 1994; Westra 1995; Light and Higgs 1996; Higgs 1997.

The nature and extent of responses of rivers to human disturbance, and the ongoing trajectory of change, and constrain, are expected to be realistically achieved in river management (Boon et al. 1992). The goals for conservation reflect the perceptions of preserving remnants of earlier ecologically stable and healthy natural ecosystems. For meeting both the ends of eco-restoration of rivers, the returning and recovery of degraded ecosystems and also catering to the need of human expectations achieve the endeavors to be made to identify the problems, chalking out eco-management strategies, and execution of the same adhering to the basic concept of ecology to repair and rectify damaged river ecosystems, mainly caused by anthropogenic activities (Figs. 8.1, 8.2 and 8.3).

8.3 Restoration and Related Terminologies: Definitions, Concepts, and Relationship

8.3.1 Definitions with Concepts

Ecological restoration (eco-restoration) is necessary because the relationship between human society and natural systems is not mutualistic as it should be. A

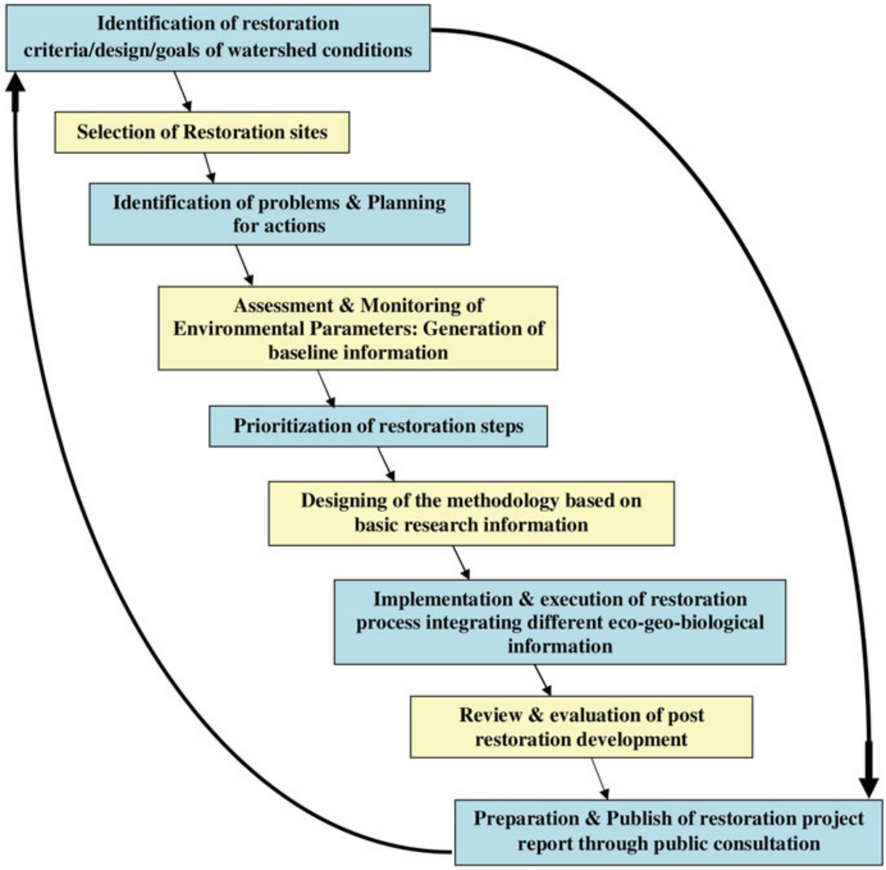

Fig. 8.1 Stepwise representation of different measures for the restoration of riverine habitats

necessary first step to correcting this situation is to achieve a balance between the rates of damage and the restoration of ecosystems (Tables 8.1 and 8.2). Meanings of the term **Restoration** have appeared to different people in different ways and thereby promoting considerable debates, conflicts, and disappointment (Hobbs and Norton, 1996). Keeping in mind the different forms of its applicabilities, the precise meaning entails the taking up of proper measures to return the structural and functional fabrics of an ecosystem to a previous state (a nondegraded, unimpaired, pristine, or ecologically healthy condition), so that the previous ecological and biological attributes and values of the ecosystem are regained (Bradshaw 1987, 1993, 1997; Higgs 2003). For example, **the Society for Ecological Restoration** (SERI 2002) state that restoration refers to the process of supporting the repairing and recovery of an ecosystem that has previously undergone degradation, damage, or distortion. Therefore, **eco-restoration** is referred to as the returning of an eco-degraded ecosystem to its earlier state of ecological health after recovering from disturbance.

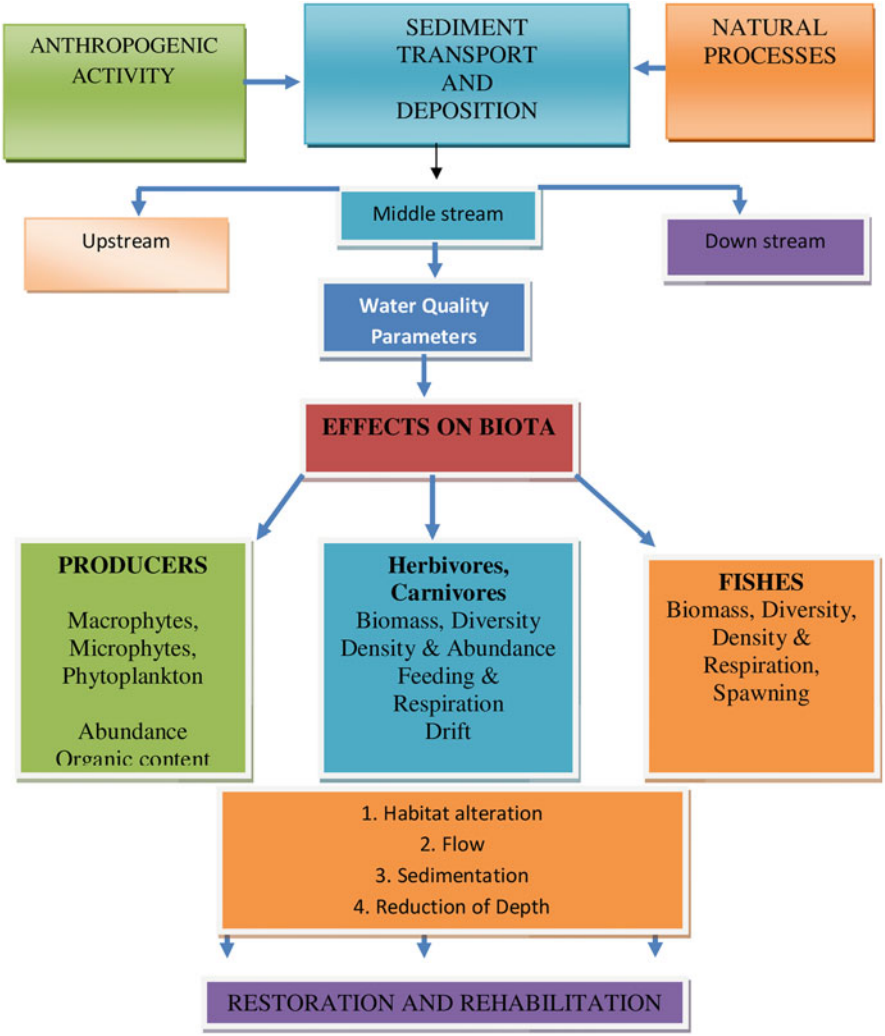

Fig. 8.2 Relationship (interlinkages and interdependence) of different activities and processes for eco-restoration program

In restoration, both the structure and functions of the ecosystem are repaired and recreated. The main objective is to develop an ecological condition similar to that of the earlier natural, proper functioning, and self-regulating system so that newly returned one can be suitably integrated with the ecological landscape in which it was existed earlier (National Research Council 1992). **Rehabilitation** is defined as per Oxford English Dictionary as, the action of restoring a thing to a previous condition or status. Although this process bears close similarity with the term restoration, there remains some incompleteness toward perfection of attending

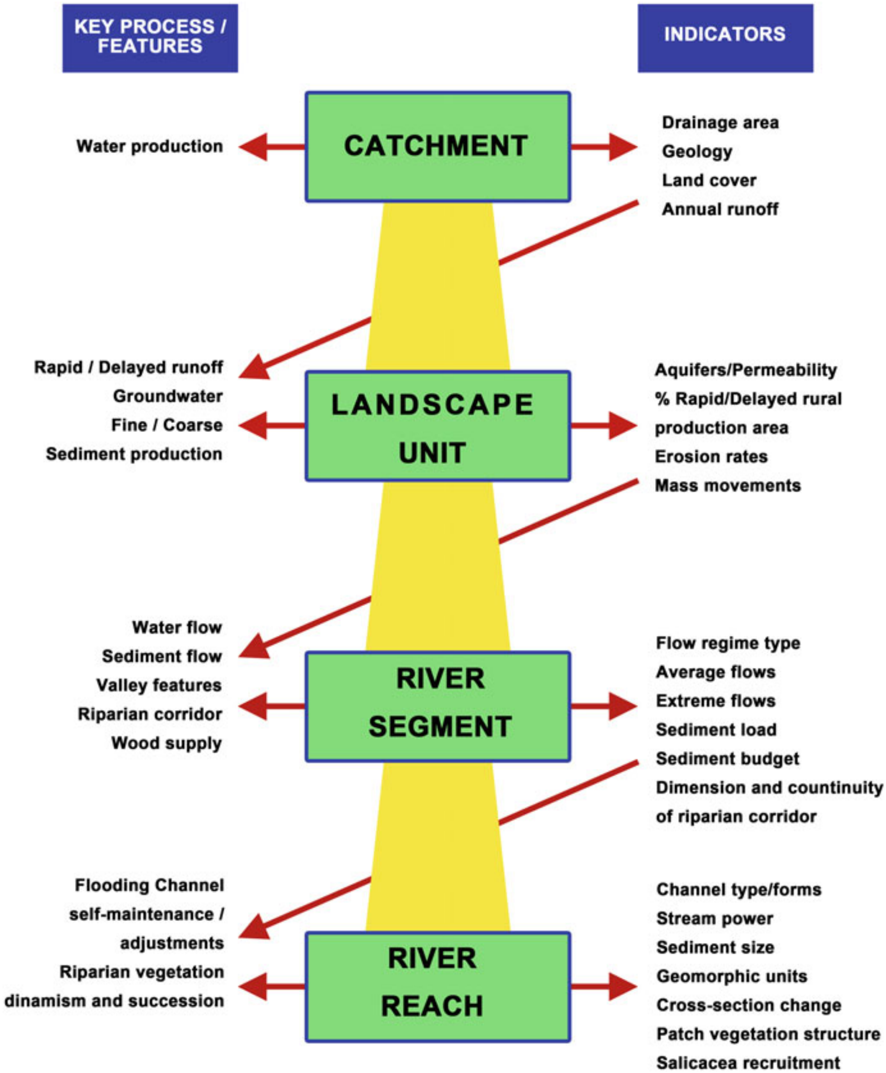

Fig. 8.3 Different eco-geo-biological processes in different riverine zones with their own uniqueness

ecological features of earlier natural state. The rehabilitated ecozone does reflect the original and natural healthy state as it had been prior to restoration (Francis et al. 1979).

Remediation is the process of remedying to rectify, for making good giving more the emphasis on the process instead of the culmination point. **Reclamation** is defined as to bring back a degraded land to its proper state. **Re-creation** refers to an attempt to achieve reconstruction of an ecosystem after being considerably

Table 8.1 Commonly used terminologies in the restoration projects

Term	Definition
Protection restoration	Creating laws or other mechanisms to safeguard and protect areas of intact habitat from degradation. Returning an aquatic system or habitat to its original, undisturbed state. This is sometimes called full restoration and can be further divided into passive (removal of human disturbance to allow recovery) and active restoration (active manipulations to restore processes or conditions)
Rehabilitation	Restoring or improving an ecosystem but not fully restoring all components. It is also called "**partial restoration**" and may also be used as a general term for a variety of restoration and improvement activities
Improvement	Improving the quality of a habitat through direct manipulation (placement of instream structures, addition of nutrients) which is often referred to as habitat enhancement and also considered as "partial restoration" or rehabilitation
Reclamation	Returning of an area to its previous habitat type but not necessarily fully restoring all functions (removal of a levee to allow river to periodically inundate an established wetland). Sometimes referred to as compensation
Creation	Constructing a new habitat or ecosystem where it did not previously exist (e.g., creating new estuarine habitat or excavating an off-channel pond). This is often part of mitigation activities
Mitigation	Taking action to alleviate or compensate for potentially adverse effects on aquatic habitat that have been modified or lost through human activity (creating of new habitat to replace those lost by a land development)

Modified from Roni et al. (2002), (2013) and Beechie et al. (2010)

disturbed leaving virtually negligible portion to be restored. In this process, the newly developed system with newly acquired ecological parameters tends to differ from the erstwhile natural ecological set ups. Such development in analyzing the ecological changes differs to a certain extent from restoration ecology which holds great promise in contributing not only important insights into the trend of ecological changes in the ecosystem but also direct and strengthen the ecological process leading to achieve the success in actual restoration efforts (Aber 1987; Jordon et al. 1987).

Ecological recovery represents a condition in which the system is allowed to move independently in order to enable the degraded system to regain desirable attributes through natural succession. This approach with a lot of uncertainty may constitute a key component of the restoration process by complementing and reinforcing of natural processes. However, human beings act as the major actor of restoration effort by possessing transparency in pinpointing the goals toward restoration and are designated as restorationlist.

8.3.2 Conservationists vs Restorationlists

1. The restorationlists put forward the views that the human beings contribute profusely for the eco-degradation and make explicit value judgments about the

Table 8.2 Common restoration strategies and their application

Restoration category	Restoration type	Example of intervention	Human impacts
Re-establish morphological river type	Initiate measures for type specific, issue based, and ecological problem solving developmental project on the river/the river floodplain system, e.g., braiding, meandering, and building of instream structures	Remove bed and bank stabilization	Moderate
		Reconnect or create side arms	Moderate
		Reconnect oxbows/ meanders	Moderate
		Restructure riparian zone (wood structure, bays)	Moderate
		Initiate to develop dynamic aquatic/terrestrial transition zone	Moderate
		Widening of small-scale river	Minimum
		Excavation and re-establishment of natural river bed	Moderate
Re-establishment of lateral connectivity/ floodplain habitat restoration	Increase/reconnect floodplain/natural retention areas	Remove/replace/lower dams	Moderate
		Lower the floodplain area	Moderate
	Initiate/create floodplain habitats	Initiate/create aquatic floodplain habitats	Minimum
Flow management	Increase residual flow	Initiate/plant floodplain vegetation	Maximum
	Increase dynamic flow	Increase and adapt dynamic (environmental) flow	Maximum
	Alter the mode of hydropower production	Mitigate hydropeaks	Moderate
	Create compensating reservoirs	Mitigate hydropeaks through compensatory reservoirs	Minimum
Temperature management	Modify turbine intakes	Create multiple entry devices and operate water release according to environmental criteria	Maximum
Sediment management	Reopen sediment sources	Remove, lower, reconstruct torrent controls, weirs, ramps	Minimum
	Active sediment input	Open riparian zones and floodplain areas	Maximum
		Addition of sediment to the river	Maximum
Restoration category	Restoration type	Example of intervention	Human impacts
	Dredge or suck sediment	Dredge or suck sediment from reservoirs and release sediments downstream in a controlled way	Maximum

(continued)

Table 8.2 (continued)

Restoration category	Restoration type	Example of intervention	Human impacts
Re-establish longitudinal continuum	Remove migration barriers	Deconstruct barrier (e.g., weir, bed sill, ramp, etc.)	Maximum
	Modify migration barriers	Rebuild a passable construction (ramp)	Maximum
Land use	Modify land use	Encourage extensive sustainable agriculture	Minimum
		Create buffer zones	Minimum

pinpointed targets of reversing deteriorating ecological changes (Meffe et al. 1997). It questions goodwill of conservationists who being the human beings are sometimes tempted to downplay ecological necessity because of achieving short-term human benefits. Because they always interact with the ecosystems and through inevitably interacting and altering the ecosystem process. This perception and assessment of the roles of conservationists have appeared to be the most critical first step toward managing and restoring any system ensuring conservation of erstwhile historical qualities.

2. The restorationlist makes an explicit commitment to the conservation of the specified system or landscape with specific, historically defined properties which are in sharp contrast to other modes of eco-management efforts by environmental managers, planners and policy makers, conservation biologists, etc. This is because the restoration promises pinpointed outcomes that can be objectively judged, leaving no room for any vagueness.
3. The restorationlist acknowledges that the return of the system to its original natural condition or its maintenance in tune with the requirements for achieving sound ecosystem health involves both active and passive processes involving the deliberate eco-manipulation for the recovery of the eco-degraded system.
4. This process of recreation of the entire system with all of its structural components and ecosystem dynamics, strong and dedicated commitments of restorationalists form the prime prerequisite.
5. In the political arena, restoration may be perceived as an alternative to conservation, a very dangerous perspective.

In fact, they are not alternatives but complementary parts of a comprehensive conservation strategy. In a sense, conservation is the objective, while restoration is one means of reaching that goal.

8.3.3 The Role of Ecological Restoration in Conservation

Until recently, protection, conservation, and management of natural areas have been the major components of conservation practice, while the role of explicit restoration has been minor or nonexistent. During the last few years, several developments have resulted in a growing interest in the practice of restoration, even among those who remain properly skeptical about the production of authentic replicas of historical ecosystems. These developments include the following:

1. Legislation requiring rehabilitation of areas disturbed by certain kinds of mining as well as restoration or creation of wetlands to compensate for **mitigation** damage to wetlands by activities such as mining or construction (Brenner 1990)
2. Increased use of restorative procedures, including use of native vegetation in engineering applications such as utility corridors, rights-of-way, and water sources (Crabtree 1984)
3. Growing interest in native vegetation as an element in ornamental landscapes (Diekelman and Schuster 1982; Smyser 1986)
4. The sheer level of ecological destruction that has made restoration necessary and attractive

Restoration has some valid and important roles to play in conservation. The number of degraded ecological systems around the world grows as the number of relatively pristine systems declines. Most lands and waters around the globe are degraded to some degree, but many are usable to important conservation areas and buffers for wild lands. Increasing attention to these degraded areas as the matrix within which centers of wilderness exist can only serve to enhance overall efforts to stem the loss of the biodiversity. Restoration ecology has appeared to hold a great promise for a successful conservation future and is likely to be the most efficient if conducted using sound ecological and conservation principles.

8.3.4 Some Central Concerns of Restoration Ecology

The development and acceptance of restoration lead to conservation that involves ecologically upgrading existing reserves, their expansion and diversification by restoration on adjacent, degraded lands, and even creation of new reserves in heavily developed or other ecologically degraded areas.

Several basic concerns common to most of the restoration projects have been placed in a more conceptual framework by Hobbs and Norton (1996) where the different steps in the restoration efforts are listed below:

1. Identify and deal with processes leading to degradation in the first place
2. Determine realistic goals and measures of success
3. Develop methods for implementing the goals
4. Incorporate these methods into land management and planning strategies
5. Monitor the restoration and access success

8.3.5 General Observations on Restoration

Jackson et al. (1995a, b) have argued that success in ecological restoration is determined by four undermentioned factors:

1. The specific ecological circumstances under which restoration proceeds
2. The various judgments made about the process
3. The values that are brought to the project or under which it must work
4. The social commitment to the project and its goals

Planning and conducting of a restoration project require consideration of a myriad of site conditions and selection of appropriate techniques from a huge array of alternatives. Out of which, special importance is the recognition that the factors addressed in restoration, essentially of those factors that limit, constrain, or influence the natural recovery process which tend to vary enormously from system to system (MacMahon 1987). The major restoration effort goes into the finding and introducing of native species in appropriate proportions while eliminating or excluding exotics, but relatively little attention is paid to patterns of distribution.

8.3.6 Uniqueness of the Restoration Process in Aquatic Systems

In aquatic systems, restoration may be as simple as eliminating the major source of phosphorus or restoring a natural hydrologic pattern or as complicated as restructuring a stream channel. In mega-scale restoration such as the Guanacaste project, restoration focuses on eliminating human disturbance regimes and changing land-use practices to allow recovery of native vegetation, assisted by intentional seed dispersal of native species. Successful restoration depends on identifying these key limiting factors and dealing with them effectively.

Despite such success, there is a tendency to skip this first step in restoration, ignoring what is there and wiping the slate clean, as it were, with plow, axe, or herbicide. Unfortunately, this strategy frequently entails destruction of elements of the functioning ecosystem that can eventually provide the best base for the restoration effort. Removal or destruction of these elements prompted to reconstruct the same which may not become impossible. An intriguing example of this principle is the recent development of restoration of prairies in succession instead of clearing the ground with conventional agro-technological measures such as ploughing or application of pesticides. Attempts to develop a universal measure of restoration of ecosystem health (Rapport 1989) through the planning and assessment of restoration process involving potential biotic components have been attempted by the restorationlists in general (Allen 1991) and as a part of different restoration projects in particular (Kieft 1991; Jansson et al. 2005). Some researchers have recommended microbes as indicators of restoration progress (Bentham et al. 1992). Most studies highlighted the significance of some species of plants having lot of potential in the restoration drives. Animals can play a vital roles in restoration efforts, but systematic study of most of them, from a restoration perspective, is still in its infancy. Much restoration simply involves manipulation of succession, either to speed up the successional processes or to halt it in an earlier state.

8.4 Guiding Principles for River Restoration

A considerable number of ecological principles and methods have been in use in restoration science pertaining to restoration processes as practiced by a number of eco-restoration practitioners (Kondolf 2011; Wohl 2005; Bernhardt et al. 2005, 2007, 2011; Palmer et al. 2007; Palmer 1997, 2012; Palmer and Allan, 2006; Roni et al. 2002, 2013) and summarizing which set of core guiding principles for sustainable river restoration has emerged as mentioned below.

8.4.1 Determination of Realistic Goals in River Rehabilitation Practice

The process of river rehabilitation begins with a judgment that an ecosystem damaged by human activities may not restrain the eco-degradation process and also recover by gaining the earlier characteristics of the ecologically healthy condition (Jackson et al. 1995a, b). Approaches to repair river systems may focus on rehabilitating **products** (species or ecosystems) directly or on **processes** which generate the desired products (Neimi et al. 1990; Richards et al. 2002). It is utmost important to know the fundamental processes of ecosystems working by way of compromising ecosystem integrity and related measures of biodiversity prior to rehabilitation (Cairns, 1993, 1997, Cairns and Heckman, 1996; Cairns and Pollock 1988).

The goal of increasing heterogeneity across the spectrum of river diversity represents a flawed perception of ecological diversity and integrity. Hence, always, heterogeneity or geomorphic complexity does not reflect an appropriate state of river ecosystem health, as in some cases, the **natural** range of habitat structure has been found to be very simple (Fairweather 1999). Simplistic goals framed in expressions such as **more is better** should be avoided (Richards et al. 2002). Unlike many biotic characteristics, physical habitat is directly liable to eco-management and maintenance through implementation of rehabilitation programs (Jacobson 2001). Counteracting the eco-degradation process focusing on the creation of physical habitat with vegetation with their other biotic associates and attaching serious attention on geomorphic characteristics of river ecosystem are an important prerequisite for proper reconstructing before sympathetic rehabilitation of riverine ecosystem (Newbury and Gaboury 1993; Barinaga 1996). Right formation of geo-morphological structure of rivers maximizes the ecological potential of a reach, in the hope that improvements in biological integrity will follow (Palmer & Poff, 1997; Palmer et al. 1997, 2005).

8.4.2 Roles of Reference Condition for Restoration Program

Appropriate reference conditions should be specified for each reach. Defining what is **natural** for a given type of river that operates under a certain set of prevailing boundary conditions provides an important step in identification of appropriate reference conditions against which the measurement of the geo-ecological integrity of a river system and evaluation of the target conditions for river rehabilitation can be possible. A **natural** river is defined as a dynamically adjusting system that behaves within a given range of variability that is appropriate for the river type and the boundary conditions under which it operates. The major thrust of this definition worth mentioning includes two salient points:

1. A **natural** condition displaying the full range of expected or appropriate structures and processes for the specific type of river under prevailing catchment boundary conditions
2. A dynamically adjusted reach that usually does not equate to an equilibrium state

Rather, the river adjusts to disturbance via flow, sediment, and vegetation interactions that fall within the natural range of variability that is deemed appropriate for the type of river under investigation. Determination of appropriate reference conditions, whether a fixed historical point in time or a suite of geo-ecological conditions, represents a critical challenge in rehabilitation practice (Higgs 1997, 2003).

8.4.3 Fixing Up and Setting of Restoration Goal

Restoration goal statements should include at least three main components:

1. Clearly identified ecological aims
2. A focus on addressing underlying causes of degradation
3. Acknowledgment of social and economic constraints on restoration (Slocombe 1998; Beechie et al. 2008)

These elements of restoration goal reflect not only legislative or organizational drivers for restoration (the ecological or biological aims) but also stakeholder values and the need to address root causes of degradation rather than symptoms. Restoration goals that are driven by species-focused legislation or nonprofit organizations often have very narrowly stated outcomes for the species, but they usually acknowledge that restoration of ecosystems is the appropriate mean to achieving that goal.

By contrast, broader restoration goals might target recovery of biological integrity or diversity and also include ecosystem restoration as a means of achieving the goal. Such goals guide restoration practitioners in choosing how to identify necessary restoration actions, how to prioritize restoration efforts, and how to help to inhibit drift in management objectives through time (Barber and Taylor 1990). It is worth noting that the terms goals and objectives are often used interchangeably, but they do in fact have distinct definitions. For the purposes of restoration planning, goals for restoration are specified as broadly stated aims or desired outcomes of a restoration effort, including the main biological outcome to be achieved. Objectives, by contrast, are specific and measureable achievements that are necessary to reach a restoration goal.

In this context, objectives are specific restoration targets that must be attained in order to achieve the broadly stated restoration goal. For example, a simplified restoration goal might be: "**Restore local fish populations by restoring watershed processes and habitats that sustain them**." Objectives needed to achieve this goal are identified by the analyses of watershed processes, habitats, and biota and might include:

1. Increase fish rearing habitat capacity by reconnecting floodplain habitats
2. Decrease stream temperatures of rearing habitats by restoring riparian vegetation
3. Reduce erosion and sediment delivery from agricultural lands

The watershed assessment also identifies specific restoration actions (or at least potential restoration actions) that are necessary to achieve the objectives and therefore to achieve the restoration goal.

8.5 Roles of Water Flows, Sediments, and Biota in Restoration Process

A restoration process should require a return of natural flooding conditions (or some simulated equivalent on a smaller scale if technology feasible) and regular access of water and biota to previously isolated floodplains, in addition to water and sediment quality improvements. Restoration in water quality in systems naturally poor in nutrients might result in lower productivity when the principal disturbance is excessive nutrient input (Wetzel 2001; Welcomme 1985; Riley and Fausch 1995; Riley 1998; Rinaldi et al. 2013, 2015a, Rinaldi 2015b; Richards and Richards 1999). Although many floodplains receive additional nutrients from farming practices and municipal wastes, their potential productivity is almost certainly depressed by physical alterations to the landscapes and hydrology, which result in highly unpredictable flood pulse and denial of access of water to much of the floodplain. This indication plus evidence of high primary productivity in natural floodplain systems suggests that tangible economic and recreational benefits should be expected from restoration attempts, in addition to increased biodiversity and decreased probability of catastrophic flooding (Beechie & Bolton, 1999; Beechie et al. 2006, 2008, 2008a, 2009, 2010).

8.6 Managing River Recovery Processes in River Rehabilitation Practice

Exactly what is required in any rehabilitation initiative will depend on what is wrong. Options may range from limited intervention and a leave-alone policy to mitigation or significant intervention, depending on how far desired outcomes are from the present condition. In some instances, sensitive, critical, or refuge habitats, and the stressors or constraints that limit desirable habitat, must be identified, and efforts made to relieve these stressors or constraints (Ebersole et al. 1997). Controlling factors that will not ameliorate naturally must be identified and addressed first. Elsewhere, rehabilitation may involve the reduction, if not elimination, of biota such as successful invaders, in the hope of favoring native biota (Bradshaw 1996). In general terms, however, most contemporary approaches to river rehabilitation endeavor to **heal** river systems by enhancing natural recovery processes (Gore 1985, 1992; Gore and Shields, 1995).

To achieve this goal, river rehabilitation activities must build on an understanding of the stage and direction of river degradation and/or recovery, determining whether the geomorphic condition of the river is improving, or continuing to deteriorate. Assessment of geomorphic river condition measures whether the processes that shape river morphology are appropriate for the given setting, such that deviations from an expected set of attributes can be appraised (Kondolf and Larson 1995; Kondolf, 2011; Kondolf et al., 2003, 2006; Maddock 1999).

Understanding of geomorphic processes and their direction of change underpins rehabilitation strategies that embrace a philosophy of recovery enhancement (Gore 1985; Heede and Rinne 1990; Milner and Petts 1994). A strategy for river rehabilitation is now being highlighted paying respect to an appealing slogan **helping a river is to help yourself** because this self-sustaining fluvial landscape originates from within the nature, to cater to the need of other gifts of nature on a large scale (Bradshaw 1996).

8.7 Restoration and Its Ecological Perspectives

8.7.1 The Science of Restoration (Restoration Ecology): Different Facets

Restoration ecology being a relatively young field of science has emerged with lot of prospect especially in addressing the not only the problems of trend of ecodegradation process but also pointing out the ways and means in mitigating and reviving the ecologically disturbed landscapes or ecosystems. However, considerable confusion exists with regard to coinage and application of terminologies in different fields of this newly emerged subject (Buijse et al. 2002; Omerod and Roach 2004; Young et al. 2005). The terms restoration, rehabilitation, enhancement, improvement, mitigation, reclamation, full and partial restoration, passive and active restoration, etc. have been in use during the last few decades to illustrate various activities toward restoring ecological processes in and around riverine ecosystem. These represent a gradient of activities from creating new habitats, to mitigating for lost habitat, to full restoration of ecosystem processes and functions and even protection.

Similarly, habitat protection, while not typically included in definitions of restoration, is a critical watershed conservation and restoration strategy that should not be overlooked. Owing to escalating continued pressure on aquatic ecosystems, including a growing human population and climate change, habitat and biodiversity losses, different restoration efforts for the protection of high-quality functioning habitats is a high priority component of restoration plans (Halder and Chakraborty 2018). In fact, habitat protection in many cases is a type of passive restoration that allows ecosystems to recover partially, because most of the efforts such as aforestation programs, are not only more beyond cost-effectiveness but fail to ensure the return of the degraded habitat to its earlier form with most of the lost biotic components (Chakraborty 2009, 2011, 2017, 2018).

8.7.2 The Justification of Undertaking Restoration Efforts

It may seem obvious to people living in densely populated and developed areas why one might seek to restore streams or watersheds, but the level of human impact and the reasons for restoration vary widely among stream reaches, watersheds, regions, and countries. Human impacts to watersheds began well before recorded history. The above factors, coupled with an increasing human population, have led to increased air pollution, highly modified and polluted rivers, and a rapid increase in number of threatened, endangered, or extinct species (Goudie and Middleton 2006). The World Water Council estimates that more than half of the world's rivers are polluted or at risk of running dry, and less than **20%** of the world's freshwaters are considered pristine (World Water Council 2000; UN Water 2009). Another key environmental aspect is the importance and economic value of ecosystem goods and services.

Until recently, the value of ecosystems was only based on the goods they might produce (harvestable fish, food, timber), but in recent years, the services or benefits we derive directly or indirectly from ecosystem functions have also been recognized. These other services include waste processing, carbon sequestering, regulation of atmospheric gases, water regulation, climate regulation, genetic resources, and many others (Costanza 1991; Cunningham 2002). In fact, the economic value of ecosystem services globally has been estimated to be **2–3** times that of the total global gross domestic product from world economies (Costanza 1991). This realization of the importance of functioning ecosystems for our economic prosperity and our very existence has led to further emphasis on protecting and restoring natural ecosystems globally.

Moreover, **80%** of human water supplies are threatened by disturbances within watershed, pollution, water resource development, and other such factors (Vörösmarty et al. 2010). Current species extinction rates are estimated to be more than **100–1000** times background (prehistoric) rates (Baillie et al. 2004); extinction rates for freshwater fauna are thought to be **4–5** times of that of terrestrial species (Ricciardi and Rasmussen 1999), and habitat loss along with degradation are believed to be the prime reason of extinctions (Baillie et al. 2004). A suite of human activities has led to degradation of streams and watersheds and impaired their use for biota, and therefore, stream and watershed restoration has become critically important worldwide.

8.8 Landscape Ecology and Its Relevance to Restoration Process

A landscape is defined as an area of land, covering an area of many hectares to square kilometers, which consists of assemblages of different but interacting patches (also called landscape elements). Patchiness mostly emphasizes on the spatial matrix of ecological processes giving due importance on the fluxes of biotic organisms, energy, and materials within and between different parts of the landscape. It represents spatial heterogeneity in which boundaries are discernible and in which different ecozones appear as contrasting, discrete states characterized by specific physical and ecological phenomena (Ostfeld et al. 1997; Sanyal et al. 2014). Patches may comprise different ecosystems (lakes, rivers, forest, etc.), different land uses (urban, agricultural, etc.) or different community types, and successional stages within a particular ecosystem, the continuous interaction among which ultimately sustain the ecosystem functioning and also maintain ecological integrity (Niemi et al. 1990; Hughes et al. 2000; Hughes, 1997; M.E.A 2005).

8.8.1 Different Components of Landscape Ecology

Landscape ecology considers three main aspects of landscapes: structure (or pattern), function(or process), and change (Turner et al. 1995) structure: it is consisted of numerous patches of varying types of configurations. The function of landscape includes a number of other components: heterogeneity: it is a complex multi-scale phenomenon, involving the size, shape, and composition of different landscape units and spatial (temporal) relations between them resulting to the following ecological events:

1. **Nutrient fluxes**: Nutrient and material fluxes across the landscape result primarily from the processes of erosion, leaching, and transport by wind and water.
2. **Alteration or change of habitat**: Habitat network can be defined as an interconnected set of habitat elements which together enable the movement of biota and enhance population survival probabilities. Fragmentation of natural ecosystems as an important pervasive change in terrestrial ecosystems across the earth. It occurs wherever land transformation results in the removal of the preexisting land cover and its replacement with other cover types.
3. **Connectivity and movement of biota**: Connectivity refers to the degree and intensity of flows (animals or materials) in between different patches.

8.9 Rivers, Streams, and Watershed Restoration: Historical Perspective

Similar to the environmental movement, the earliest stream restoration efforts were largely undertaken by hunters and fishermen. While efforts to minimize erosion and protect water supplies and agricultural land date back thousands of years (Riley 1998), the first substantial efforts to restore streams are thought to have been made in the late **1800s** by local fishing clubs in the **USA**, and river keepers on British estates are interested in improving salmon or trout fishing (Thompson and Stull 2002; White 2002).

More formalized endeavors to restore streams were undertaken in the **USA** in the early part of the twentieth century (Thompson and Stull 2002). After words, techniques were developed largely based on engineering approaches attempting to create pool habitat or a static stream channel and often treated symptoms (lack of pools) rather than underlying problems (excess sediment, lack of vegetation along river channel, and woody debris) (Riley 1998). The **1940**s and **1950**s witnessed an increased emphasis on planting of vegetation to stabilize banks; however, these efforts were often not viewed as favorably as in stream structures and hardening of banks, which were seen as quicker and more permanent. Expansion of state and federal stream restoration programs in the **USA** continued from the 1950s through the 1980s. Following years of overgrazing and other human activities, riparian vegetation began to recover along numerous streams in the **USA** and **Canada**. The late **1980**s and early **1990**s have witnessed rising awareness toward assigning importance of riparian areas and a better understanding of ecological, physical, and biological processes with the objective of understanding the impact of land use and human activities on those processes and habitats for aquatic biodiversity.

This was initially based on extensive studies on forested streams in the Pacific Northwest of North America but was later based on studies in a range of land uses and eco-regions. The results of these studies led to recommendations for a watershed or ecosystem approach to management and a growing call for looking beyond an individual stream reach when planning restoration (Beechie and Bolton 1999; Roni et al. 2002; Hillman and Brierley 2005). From the 1990s until today, restoration efforts have slowly been changing from a focus on localized habitat improvement actions at a site or reach scale (which often overlooked the root causes of habitat degradation) to a more holistic watershed or ecosystem approach which tries to treat the underlying problem that has led to the habitat degradation.

8.10 Broad Philosophical Views About Scientific Uncertainty

During the nineteenth century, the methods and tools of science and technology are applied for increasing understanding of the natural world in order not only to use the natural resources for human utilization but also to enable robust predictions of its future states. This perception strengthened with confidence in science contributed to beliefs that nature could be controlled and rendered useful to humankind (Latour et al. 2012). Several environmental laws and regulations have been formulated and enacted for the so-called well-being of the environment or human health mostly through the government regulatory agencies attempting to demonstrate harm from development activities and also to identify standard that is used to meet the normal standard of scientific proof (Brown 1995). Consequently, information of the public policy and decision-making have revealed that perturbation has had an effect on the environment or human health, but, say, only at the **70–90%** confidence level the null hypothesis that there is no effect from the factor or perturbation is accepted (Latour et al. 2012).

8.11 Problems Being Encountered in Restoration Projects

In course of analyzing of the value-laden issues in restoration for ecological as opposed to primarily or exclusively economic development goals, several types of problems were highlighted by Cairns (2003) which are as follows:

Firstly, some restoration projects are carried out on habitats different in kind from those altered or destroyed. For example, partial restoration of rivers and associated wetlands that once occupied a particular lowland area can cause the destruction of an upland forest. Restoration of rivers and/or wetlands having immense ecological value may cause unanticipated ecological change or harm by way of sacrificing a relatively undamaged habitat.

Secondly, with few exceptions, restoration projects for most of the rivers and other ecological landscapes have been undertaken and executed in order to support and strengthen the utilitarian values by offering different anthropocentric commodities to human beings which in turn poses and invites conflicts with restoration goals for non-anthropocentric reasons.

Thirdly, undertaking restoration programs for rivers with the lack of baseline information and non-availability of appropriate scientific methods and tools to predict long-term outcomes may result to uncertain outcomes due to the development of some unpredictable events like floods or droughts.

Fourthly, restoration efforts focusing on single species or ecosystem attributes might eliminate those species that had initially colonized at disturbed areas after being endowed with the power same time tolerance to variety of anthropocentric stresses. However, restoration projects might result in the displacement of species tolerant to human activities with those less tolerant, at least in the short term.

Fifthly, the tolerant species with the power of overcoming anthropocentric stress and the succession processes are utilized in the process of ecological restoration as human friendly or dependent species.

The ecological precondition in respect of foods, shelter, and breeding avenues for making the return of an indigenous species include a thorough and continual interventions (value-laden judgments, evaluations, assumptions, and inferences toward management of ecosystems, including geo-hydrological, and other water resources) by researchers and environmental decision-makers toward their re-establishment (Lemons and Brown 1995). For example, people have to decide the ecosystem parameters that are more important to base judgments on and often with little or no available empirical information of ecosystem parameters which should be considered either independently or synergistically in order to predict and evaluate the threshold values in respect of environmental or health impacts.

8.12 Assessment of Ecological Characteristics: Prerequisites for Eco-restoration Planning

Ecological restoration appears to be successful only by ensuring the effective functioning of the river corridor, instead of only focusing to re-establish some of the structures or to trigger the initiation of a particular physical or biological process. Structurally (matrix, patch, corridor, and mosaic) and functionally (conduit, filter, barrier, source, and sink), rivers are characterized by the habitat.

A number of geophysical attributes that determine the variability of river functioning are as follows:

1. **Connectivity**: This being a measure of the dimensions of a river promotes transport of materials and energy and movement of flora and fauna which are intervened and affected by the breaks in the corridor and disrupting the continuity between the stream and adjacent land uses.
2. **Width**: This refers to the distance across the stream and its zone of adjacent vegetation cover which is disturbed by edges, community composition,

environmental gradients, and other disruptions in adjacent ecosystems, including human settlements.

3. **Habitat**: It is a term used to denote a place having certain space, food, and water, where plants or animals inhabit to complete their life cycles (birth, settlements, growth, feeding, reproduction, and death) and establish viable populations; the size, density, and genetic variation contribute to establish a stable biological community (collection of several populations), which vary within known boundaries over time. Besides, corridors of the streams and rivers are linked to small habitat patches and thereby create more complex habitats which support higher biodiversity due to the development of habitat heterogeneity. Broad, non-fragmented, and diverse streams help flourishing of more species by providing more suitable habitats, structured and characterized by a multitude of macro and microclimatic factors such as soils, vegetation, elevation, topography, and hydrology, and also mode of human uses patterns.
4. **Conduit Function**: Conduit function is meant for the expanding of easy passage to ensure the flow of energy, materials, and organisms, and a stream or river has become conduit for collecting and transporting water and sediment along with aquatic fauna (fish, migratory birds and mobile wildlife) and other biochemical entities. However, due to such movement along the streams in many other directions, the corridor takes up lateral and longitudinal conduit functions.
5. **Filter and Barrier Functions**: Corridors of rivers and streams may act on one way as filters, allowing selective penetration of energy, materials, and organisms or restrict the movement of many species as barrier. Even such distinctions perform beneficial roles by decreasing water pollution, reducing sediment transport, and restricting plant communities and some less mobile wildlife species by acting filter or barrier. Moreover, vertical movement of materials, energy, and organisms maintaining perpendicular orientation to the flow of the stream is most rigidly filtered, whereas other materials moving parallel to the stream corridor, or along the edge, are selectively filtered. Besides, riparian vegetation acts as filter for the nutrients, sediment, and water which undertake movements over the land.
6. **Sinking Functions**: Owing to the continuous lateral interactions of rivers or streams with bordering landscapes experience exchange of materials (water, energy, and organisms) for the mutual benefits of both in one hand and function as sinks absorbing the dumped materials released on the surrounding land mass. Stream corridors acting as reservoirs of surface water, groundwater, sediments, vegetation, faunal assemblages, nutrients, and stored energy serve also as a sink for all kinds of substances. Forman (1997) opined threefold of roles of floodplain vegetation as both sources and sink functions which are (**1**) reduction in the intensity of flooding to downstream by offering frictional and absorptional resistance, (**2**) controlling the intensity of movement and deposition of sediments and other substances at the time of flood, and (**3**) acting as the steady source of detritus, humus, and other plant litter- derived chemical to enhance nutrients pools of soils and water.
7. **Function to Maintain Dynamic Equilibrium**: The ecological characteristics of the rivers and stream corridors always undertake steady ecological changes,

revealing a dynamic form of stability even without any human intervention. This stability represents that state of a system which is able to remain intact within a range of some conditions. Such state of affairs, technically designated as dynamic equilibrium, is required to be maintained within the river ecosystem by virtue of having an active series of self-correcting mechanisms in order to overcome stress factors generally developed due to external disruptions of the normal conditions of the ecosystem so that preservation of a self-sustaining condition is possible. However, removal or controlling of the source of a disturbance may enable a stream system to return to its working condition in a reasonable amount of time.

In the planning stage of eco-restoration of rivers, or a stream, the abovementioned eco-bio-geological attributes (size, length, width, depth, volume of water, sediment profiles, nature of riparian forests, etc.) and their functional potentialities within the channel itself, riffles, pools, glides, rapids, and backwaters should be given highest priorities and allowing higher recovery time. Besides, the removal of external stresses allows restoration by recovering the ecosystem from the eco-degraded stage to the stage having dynamic equilibrium.

8.12.1 Classification of River and Stream Types as a Restoration and Management Tool

River restoration has assumed great importance during the last few decades based on the increasing realization of the peoples regarding the ongoing deterioration of the ecological health of the rivers because of the alteration of hydrology, water chemistry, and biology of rivers with their unintended consequences in urban (Bernhardt and Palmer 2007) and other areas (Bernhardt et al. 2005, 2007). Such restoration efforts with an aim at achieving long-term stability of the system are in need to understand the natural hydrology of the degraded river systems coupled with the dynamic equilibrium of the geomorphology. Besides, proper understanding on the patterns and seasonalities of life history of those selected species that are being managed and re-established (Jansson et al. 2007) and the salient aspects of desired ecosystem functions constitute the important prerequisite for successful restoration. One of the prime objectives of key restoring rivers and streams focuses on both existing natural and altered morphology. Such classification of river systems with an emphasis of the reasons behind the modifications of river morphology has become the central responsibility in restoring river systems (Kondolf et al. 2006).

Rosgen system of river classification has been considered as one of the most popular ones which includes two modes of classifications Rosgen, 1994:

1. The first one characterizes the channel and valley shape, slope, and pattern (confined or wide valley).
2. The second one being determinant of stream classification emphasizes on the width, depth, channel entrenchment, sinuosity, slope, and substratum type in the stream (sand, gravel, cobble).

The main objectives of such classifications highlight the following:

1. Based on existing river morphology, river behavior is predicted.
2. Specific hydraulic and sediment relationships appropriate for the type of stream can be developed.
3. Assessment methods of reference reaches can be provided.
4. Characterizing of stream morphology and condition with suitable and common frameworks can be possible.

8.13 Role of Plant Diversity in Restoration Process

Bioremediation of degraded soil and water deforestation, mining, manufacturing, and other anthropogenic activities have resulted in the conversion of large tract of healthy soil into a degraded wasteland often contaminated with toxic elements like heavy metals, pesticides, etc. Plants that cover the soil ensure the environment of barren non-fertile soil with organic humus and thereby restore moisture content and invite other form of lives (both flora and fauna) and also act as potential agent for bioaccumulating within them toxic substances like metals in order to restore the health of soil (Table 8.3).

Table 8.3 Differential patterns of heavy metal uptake by algae (Pradhan et al. 2008)

Concentration factor	Metal (s)	Type of algae	References
3700	Zn	Green algae	Harvey and Patrick (1967)
21,600	Zn	Diatoms	Harvey and Patrick (1967)
Ca. 4000	Zn, Cd, Cd	*Chroococcus paris*	Les and Walker (1984)
2,000,000	Cd	*Chlorella pyrenoidosa*	Hart and Scaife (1979)
<4000	Cd	*Chlorella pyrenoidosa*	Sakaguchi et al. (1979)
1000–100,000	Cd, Pb, Hg	Various species	Hassett et al. (1981)
4000	U	*Chlorella* sp.	Nakajima et al. (1981)
>100,000	Pu, Am, NP	Various species	Fisher et al. (1983)
500–30,000	Various	Various species	Tarifeno et al. (1981)
3056	Cu	*Chlorella* sp.	Wong and Pak (1992)
869	Ni	*Chlorella* sp.	Wong and Pak (1992)
2327	Cd	*Chlorella* sp.	Solen et al. (1985)
570–31,000	Pb	Various species	Trollope and Evans (1976)
2000–25,000	Pb	*Cladophora glomerata*	Vymazal (1990)
16,000–20,000	Pb	*Cladophora glomerata*	Keeny et al. (1976)
620–7700	Pb, Cd, Zn, Cr	Green algae	Becker (1983)
67–34	Cs-137	Green algae	Tateda and Koyanagi (1994)
11–92	Cs-137	Red algae	Tateda and Koyanagi (1994)
7900	Ni-63	*Scenedesmus* sp.	Folson et al. (1987)

8.13.1 Bioremediations and Its Different Forms

Bioremediation being a recently emerged biotechnological tool for removing the harmful toxic substances from the environment by using biological organisms, especially the plants and microbes which bioaccumulate and biodegrade the substances with higher toxicity to less toxic forms.

8.13.1.1 Phytoremediation

The use of selected plants to clean up soil and water contaminated with pollutants has been emerging as an innovative tool for in-site remediation which emphasizes both the biological and physical properties of the soil. Five main subgroups of phytoremediation have been identified.

8.13.1.2 Phytoextraction

Plants remove metals from the soil and concentrate them in their harvestable parts (Kumar et al. 1975).

8.13.1.3 Phytodegradation

Plants along with associated microorganisms degrade organic pollutants (Burken and Schnoor 1997).

8.13.1.4 Rhizofiltration

The roots of the plants absorb metals from wastewater of the streams (Dushenkov et al. 1995).

8.13.1.5 Phytostabilization

Plants reduce the mobility and bioavailability of pollutants by immobilization (Vangronsveld et al. 1995).

8.13.1.6 Phytovolatilization

Plants volatilize pollutants from the soil into the atmosphere. Hyper-accumulator plants are capable of accumulating metals to a concentration of more than **100** times of that plants designated as non-accumulators (Raskin and Ensley 2000). So far, **400** species of plants having such potentiality have been recorded which constitute less than **0.2%** of all angiosperms for this purpose (Baker et al. 2000). In the wastewater treatment process, it has been found that some aquatic macrophytes along with a number of algae act as important sink of many toxic substances especially heavy metals (Table 8.3). Different algae (*Chroococcus* sp., *Chlorella* sp., *Cladophora* sp., etc.) have been used profusely as metal removers. Besides, several macrophytes, like Lemna (duckweed), Spirodela, and Wolffia, are being used as alternatives to microalgae. Another advantage is the harvesting of their biomass. One interesting aquatic fern is the genus *Azolla* which contains nitrogen-fixing cyanobacteria (*Anabaena azolla*) and a bacteria (*Arthrobacter* sp.) having nitrogenase (Costa et al. 1994). This *Azolla* sp. is being used as bio-fertilizer in one hand and water purifier.

Rivers are not only water canals but also complex corridors with water and other features. Riparian vegetation is completely integrated within this environment, contributing to its good health. Flooding, erosion, and sediment deposition are the engines of this natural infrastructure.

River restoration meaning a good repair of eco-degraded riverine tracts requires good diagnosis of the state of ecological health of the river system-based baseline ecological information, mostly on the diversity, distribution, and trophic interactions among biotic components. Information pertaining to phenology of plants (seasonality of life history events such as breeding and migration, population dynamics, etc.) and also an understanding of both local and regional patterns of plant species diversity after selecting appropriate reference conditions are required for planning riparian restoration with the plants.

Baseline information on the existing multidimensional distributions of species at spatial scales matching with restoration planning designs of historic biogeographic distribution have appeared to enhance restoration planting success and ensure sustainability in long-term ecosystem functioning. Experiences and knowledge base developed out of such restoration efforts, the match/mismatch hypothesis, being a key concept in seasonal community dynamics (Nakazawa and Doi 2012), has been generated which states that the close coincidence of most energy-expensive period of the consumer's reproductive phenology with the peak period of the resource availability, results higher recruitment of the consumer (Cushing 1990).

8.13.2 Role of Certain Biodiversity Components for River Across Biogeographic Patterns: Relevant Hypothesis

Conservation of biodiversity being critical component of ecological restoration worldwide (Gann and Lamb 2006) has become very pronounced in developing scientific principle for the restoration of river ecosystem (Ward and Tockner 2001). In certain regions, restoration efforts have displayed similarity in some parts and especially in certain ecosystems of the world, covering sufficiently large areas such as large-scale biogeographic regions, the species diversity from where are described and represented in restoration planning. Certain species may determine impact making the ecosystem functioning (bank stability, nutrient processing, wildlife habitat, etc.) favorable for a host of another group of species for their subsequent colonization after initial settlement and proper establishment of the pioneer species in the newly developed favorable ecological condition. Although the approach with a suitable target species seems to contribute for more efficient ecosystem function on a localized territory (Dufour and Piégay 2009), but it can also render considerable influence for longer-term successional trends and composition of regional floras.

Regional understanding of species distributions appears to be a necessary prerequisite complement the local level planning and execution efforts to strengthen the larger biogeographic strategies aimed at ecosystem restoration. Considering different views, observations, and interpretations on the roles of biodiversity on restoration processes (Mayer et al. 2003; Lemke et al. 2017a, 2017b, 2017c, 2017d; Parker 1997), the following hypothesis can be developed:

1. It can be hypothesized that although for successful restoration of riverine environment, biodiversity provides localized genotypic source materials and ecosystem services, the actual role of biodiversity should be considered from the point of biogeographic elements and species diversity, species richness, and underlying environmental gradients in order to address a broader range of restoration practices with regard to appropriate location and diversity targets.
2. It is also hypothesized that intermediate connectivity to a river facilitates the inputs of propagule from rivers to wetlands, in contrast to other modes of connectivity, excessive of which retard recruitment, resulting to lower biodiversity development, whereas insufficient connectivity leads to eliminate less competitive species and also cause hindrance to the recruitment of new species. As a consequence, differential load of nutrients in the water bodies causes a decline in the species richness due to the flourishing of only some specialized species, whereas intermediate nutrient levels promote the co-occurrence of species having contrasting nutrient requirements.
3. The most frequently flooded channel supports the highest species richness and enables the settlements and flourishing of the rare and fugitive species, as because of floods compensate competition by scouring sediments and plants which in turn promote for the development of regeneration niches for propagules.

Out of such observations, it can be stated that conservation of biodiversity necessitates to activate propagule sources at the level of the river landscape.

8.13.3 Niche Theory and Ecotypes: Roles in Restoration

The term restoration ecology being an important facet of applied ecology involves restoration of habitats with a range of permissible ecological parameters, recovery of overexploited fisheries, controlling of invasive species, afforestation to enhance the green coverage, etc. (Ormerod 2003). The most acceptable solution for land reclamation is to undertake massive plantation programs which certainly stabilize the land surface by arresting the erosion of surface soils and also by promoting self-sustaining succession of a more complex community (Bradshaw 2002).

Selection of suitable plant is species based on their ability of tolerance of toxic metals and also to occupy fundamental niches that possesses extreme ecological conditions. Moreover, ecotypes (genotypes within a species having different fundamental niches and wide range of distribution experience different kinds of environmental pressures) are subjected to varied forms of natural selection pressures to acquire different variants of the species at different sites and contribute considerably in the restoration of degraded lands with metallic pollutants because of their evolved resistance against metals in the mined area.

The word "**ecotypes**" highlights the roles of genetically determined traits in making differences between and within populations of a species supported by their environments. In contrast, evolution drives the development of characteristics of different members of populations that diverge from each other if the following two criteria are satisfied:

1. There is sufficient heritable variation on which selection can act.
2. The forces leading to divergence are endowed with lot of strength in order to resist the intermingling of individuals and thereby hybridization process t different eco-regions.

Two specialized populations become differentiated most conspicuously among organisms that are immobile for most of their lives as because motile organisms can adjust and survive in a changing environment by escaping, recoiling, and retreating an adverse and lethal environmental conditions and arriving at a favorable ones. Sessile and immobile organisms are handicapped for having such access to favorable and conducive environment, and they are prone to mortality in adverse environmental conditions, where they settle, exposing themselves to the mercy of forces behind natural selection in a peculiarly intense form.

8.13.4 Response of Fish in the River Restoration Process

Anthropogenic activities such as channelization alter many of the physical features and disrupt the natural pool-riffle sequence of a stream and thereby hamper the abundance and distribution of juvenile and adult fishes (Bayless and Smith 1964; Jones 1975). The restoration is measured to revive the natural ecological condition in the streams and rivers involving steps to reverse man made eco-degradation by increasing habitat diversity in order to provide favorable ecological conditions for the different aquatic faunal components including fishes of various sizes and species which get shelter with steady supply of foods and undertake reproduction and breeding (Gore 1992). In turn restoration practices are also in need for the receiving of feedback responses of the rehabilitated organisms so that better improvements to the ongoing restoration practices in respect of different ecological attributes such as the improvement of water quality can be ascertained. Fish as the apex predator in the aquatic system are supposed to provide some inputs for the success of the restoration projects. The striking declining of the numbers of indigenous and endemic fish species across the world mainly due to several anthropogenic activities such as habitat destruction, non-judicious exploitation, aquatic pollution by pollutants from both point and non-point sources, introduction of exotic species, etc. has drawn the attention of not only the fishery scientists, ecologists, and environmental planners but also common peoples of the society including the politicians and administrators. With such ecological, economical, and social implications in mind, the importance given to the restoration of fish communities has been increasing during the few decades. Restoration activities in this respect have focused on improving local habitats and stream corridors, sometimes by creating fencing to restrict the entry of unwanted biota including the livestock, developing fish passages, or establishing instream physical habitat. Different stages (eggs, spawn, fry, juveniles, and adults) over the life span of a fish species need different forms of resources along with a wide range of habitat requirements which are seldom met by the restoration process. Fish remain within the aquatic ecosystem not only as an isolated and independent group of faunal component but share their habitats with other fauna such as freshwater mussels, many species of which are very sensitive ones displaying their responses to the habitat disturbances (fragmentation of the remaining habitats, persistent sedimentation, pesticides, and exotic species) and are used to detect the ecological changes as bioindicator. Therefore, another goal of the stream restoration is to ensure preservation of not only fishes but also associated biota based on the baseline information on their eco-biology like fish and other mussel species which are introduced into the habitat.

Some of the fish species are found to be critical to overall river health and also in determining the occurrences and abundance of other members of the fish community for three reasons:

1. The genus includes those species which comprise more than half of the total fish biomass in the permanent habitats within the rivers and floodplains (Bonetto 1994).
2. The larvae of those species serve as novel source of food for the consumption of the fry and juveniles of other large piscivorous fish species that inhabit in the same habitat.
3. The adults of these fishes ingest fine detritus and further process the organic matter and ultimately produced or transported by processes linked to flood pulse dynamics.

Detritivorous fish species by virtue of their abundances are not only affected by biogeochemical cycles but in turn can influence even at large scale biogeochemical processes of floodplain rivers. In addition detritivorous species play very critical roles in the ecology (both carbon and nutrient cycling) of large rivers by assimilating primary production from highly productive floodplains and transport this carbon to other river areas and even to nutrient-poor ecosystems where they subsidize fish production (Winemiller, 1990, 2004, 2007; Winemiller and Jeppsen 1998). They are considered as ecosystem engineers as they can substantially affect the overall fluvial bioenergetics budget (Taylor, 1999, 2007; Flecker 1996). Understanding of all these interlinkages, interrelationships, and interdependences among different aquatic biota in respect of the changing ecological conditions can act as an important prerequisite for undertaking of an effective restoration venture.

8.13.5 Response of Water Birds as an Indicator of Restoration

Different eco-regions associated with large rivers and other freshwater wetlands support continentally diversified water birds species and their foraging guilds after sustaining extensive anthropogenic degradation, especially during period of their migration (autumn and spring) where they were found to exhibit effective contribution toward restoration, as revealed from an extensive study in the Illinois River Valley (Hagy 2017). It has been noticed that different large rivers in the Upper Midwest region of the **US** region have been experiencing loss and eco-degradation of river-associated wetland areas during the last two centuries (Morrison 1986; Dahl 1990) after getting isolated from portions of their floodplains (Tockner et al. 1998, 1999, 2000; Tockner and Stanford 2002), filled with sediments (Bellrose et al. 1983), colonized by invasive species (Bajer et al. 2009), or degraded in other ways (Jackson and Pringle 2010).

Water birds inhabiting in wetlands serve as an indicator of the changing ecological condition succession, hydrologic modifications, and restoration success of the wetlands (Niemi et al. 1997; Austin et al. 2001; Gawlik 2006; Kajtoch et al. 2014; Figarski and Kajtoch 2015). Water birds and their foraging habitats were identified as potential indicators having specific biological characteristics, ecological processes, and wetland succession stages and relevant research information which can be used to evaluate wetland restoration and management progress (Parrish et al. 2003; TNC 2006).

On assessing different bio-ecological attributes pertaining water birds ecology and behavior such as abundance and diversity and behavior of water flow and productivity using brood counts as an index, it was hypothesized that water birds would quickly colonize wetland habitats, and taxonomic composition would change over time in response to changes in habitat structure, especially species composition, and extent of coverage as well as water bird productivity would increase over time as water bird species colonized emergent vegetation communities and other habitats (Hine et al. 2016).

Instead of tracking water bird, densities of water birds were compared from other regional water bodies across a continuum of river connectivity enjoying hydrological connections to the Illinois River through which the habitats of water birds received flood water during flooding (spring and summer) which was found to prevent the growth of emergent macrophytes and submerse other aquatic vegetation alongside enhancing turbidity by erosional input of flood waters and introducing common fishes which in turn decrease wetland foraging habitat quality for water birds by consuming vegetation (Sparks 1995; Ivey et al. 1998; Stafford et al. 2007; Bowyer et al. 2005; Bajer et al. 2009). The energetic carrying capacity for water birds has been found to be greater on a per unit basis in moist soil wetlands than emergent marsh habitats (Soulliere et al. 2007; Straub 2008). Hagy et al. (2016) highlighted the strong selection preferences of some water bird species and guilds for emergent marsh vegetation regardless of disturbances. Hine et al. (2016) observed a rapid expansion of persistent emergent, submersed and floating-leaf aquatic vegetation communities produce and render valuable sources of foods to be consumed by species such as American coots and gadwall rather than mallard. Besides, foraging rates of migratory birds can help predict breeding phenology (Morrison 1986; Arzel and Elmberg 2015), food availability (Loegering and Fraser 1995; Johnson 2000), seasonal changes of habitat composition and quality (Lyons 2005), and average size and brood density of water birds (Hine et al. 2016) within the aquatic systems.

Declines in water bird brood because of reduction in wetland area during high-water conditions of flooding, prolonged draught, etc. can be compensated by the rapid colonization of migrating and nesting water birds species and guilds, concurrent with changes in vegetation communities and water stabilization as conditions different from the **intermediate** stage of disturbance and facilitating a transition of disturbed habitats to conducive ones by achieving climax community (van der Valk and Davis 1978; Hine et al. 2016).

Based on long-term and large-scale research surveys, water birds have been seen to become an effective indicator of ecosystem changes which help to overcome pitfalls associated with monitoring short-term changes in populations at particular sites without a baseline (Niemi et al. 1997; Stolen et al. 2005; Bajer et al. 2009). Eventually, stable and high-water levels coupled with the involvement of diverse stakeholder groups may result in declining productivity and foraging habitat quality for wildlife, and thereby management actions engaging the regional conservation community and general public with a user-friendly evaluation process are the need of the hour (Bloomstein et al. 2005; Sparks et al. 2016; Tierney et al. 2009a).

8.13.6 Roles of Fungi in the Removal of Cd(II) and Pb(II): A Step Towards Eco-remediation and Eco-restoration of a Tropical River

Live and dead biomass of organisms, both fauna and flora, are also found to be effective for the removal of pathway of diversified forms of toxic heavy metals as found in wastewater. Among the flora and fauna, fungi are able to produce high amount of biomass, and they have strong heavy metal removal efficiency (Gruszecka-Kosowska and Kicińska 2017; Kapoor et al. 1999). The potential of soil inhabiting fungi of freshwater river ecosystem for bioremediation and also their roles in facilitating eco-restoration have been proved through the power of those fungi in the bioaccumulation and also for the removal of toxic heavy metals from the aquatic system.

One soil-inhabiting fungus, *Aspergillus penicillioides* after being isolated from different stretches of Subarnarekha River, a trans-boundary river, in India (upstream, middle part, and extreme downstream), has shown to highlight maximum capability heavy metal tolerance up to a level of **1000 ppm** of **Cd(II)** and **Pb(II)** mainly because of their power to produce huge amount of **exopolysaccharide** (**EPS**) that helps in maximum heavy metal immobilization. Sixteen **(16)** fungal strains after being isolated from the soil samples collected from different eco-regions of the same river within its stretch in the state of West Bengal, India, were purified, and allowed to grow in the culture media, prepared with metal concentration (**40 ppm**) supplemented with **PDA** medium. In such microbial laboratory set up, all the strains undergone proper processing for growth and screening. The suitable one having the power of performing the dual functions such as the removal of both **Pb(II**) and **Cd (II**) were selected, and among them, one strain (**F12**; *Aspergillus penicillioides*) showed the highest metal-tolerant ability up to **1000 ppm**. The strain was identified using both. Both morphological and molecular studies revealed that *A. penicillioides* is an euricious species having the ability to inhabit in a wide range of habitats with fast-growing (white, and yellow, yellow–brown, brown–black, or shades of green) colonies mostly composed of dense felt of erect conidiophores. This thin and non-sporulating fungus exhibited their potential to treat petrochemical effluents chemically characterized by short-**chain fatty acids (SCFA**) endowed with acetic acid, propionic acid, isobutyric acid, n-butyric acid, isovaleric acid, and n-valeric acid (Kushner 1978). Maximum metal removal ability by both dry biomass and **EPS** against **Pb(II**) and **Cd(II)** was recorded at **pH of 6.0** and in the temperature range of **25 °C–35 °C**. It showed the maximum heavy metal removal efficiencies were observed after a period of 6 days of incubation having concentration of **40 ppm** of **Cd(II)** and **Pb(II)**. **SEM** analysis of these fungal samples grown in medium containing equal concentration of both **Pb(II)** and **Cd(II)** and prepared from the biomass or **EPS** has revealed the efficiencies of simultaneous trend of accumulation and removal of both metals (Figs. 8.4, 8.5 and 8.6). Maximum metal accumulation observed in **EPS** in comparison with biomass, whereas almost double percentage of **Pb(II)** have been removed than **Cd(II)** by either **EPS** or dry biomass when supplemented combinely with equal concentrations. Maximum absorption as recorded in **EPS** is supposed to be due to the presence of high porosity than dry biomass.

FTIR analysis have shown the presence of a mosaic of different functional groups in the biomaterials which are responsible for binding of metal ions, including amide **(**$-NH_2$), carboxylate **(–COO–)**, thiols **(–SH)**, phosphate (**PO** $_4$**3-)**, and hydroxide **(–OH)** (Wang and Chen 2009; Gupta et al. 2010; Çelekli et al. 2010). Their intensity depends mainly on the nature, number, affinity, and distribution of biopolymers. In such context, an understanding of the underlying scientific principles for explaining the mechanisms of binding of certain metal ions with the proper

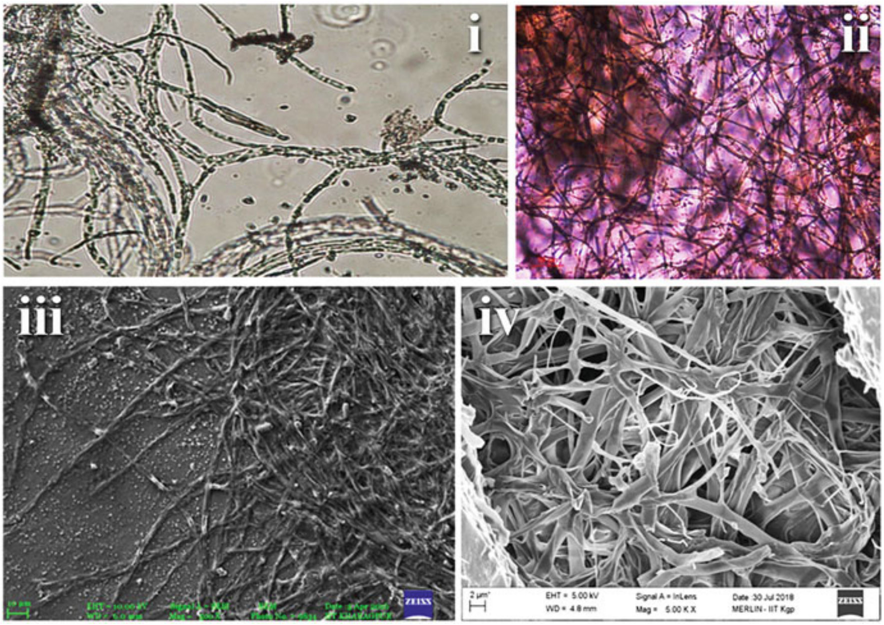

Fig. 8.4 Different fungal strains from the bottom sediments of Subarnarekha River, West Bengal, India, having their biomedical activities. (After Paria and Chakraborty 2017)

identification of functional groups has appeared to be very important. The asymmetric and symmetric **C–O=C** stretching vibrations are expected to appear at **1150–1250** and **1000–1050 cm^{-1}** (Silverstein et al. 1991). The appeared peak at **1036 cm^{-1}** corresponded to the interaction of **C–O–C** symmetric stretching mode. Further, the recording of a number of appearance of **1036 cm^{-1}** is due to the vibration associated with **(–CN)** stretching which involves a carbon of free structure and the nitrogen of the amino group (Lal et al. 1982). Interestingly, **FTIR** spectrum obtained from isolated mycelia biomass after treating the fungal cells with **Cd II** metal showed the value shift of **1036 cm^{-1}** peak to **1023 cm^{-1}** which confirmed that **Cd(II)** ion tends to affect the **C–O–C** bond. Simultaneously, **965 cm^{-1}** for **Pb(II)-** treated biomass correspond to **C–O** stretching vibration.

The absorption band at **965 cm^{-1}** is attributed to **C–O** stretching to the phosphodiester and ribose sugar of **DNA** (Chiriboga et al. 1998). Therefore, it seems that both metal ions of **Pb(II)** and **Cd(II)** directly target to **DNA** and bind to **C–O** stretching of ribose and phosphodiester bond. The peak at **1163 cm^{-1}** attributes to the vibration of **C–O** bond of ribose sugar. Further, the peak at **1741 cm^{-1}** is corresponding to the vibration of **C=O** ester which also disappears after metals (**Pb II and Cd II**) treated biomass. Therefore, mycelial biomass-associated metal removal occurs due to the vibration of **C–O–C** and **C=O** ester bond. The vibration frequency observed at **1067 cm^{-1}** is responsible for **C–O** stretching which have been shifted to **985** and **965 cm^{-1}** for **Cd(II)** and **Pb(II)-**

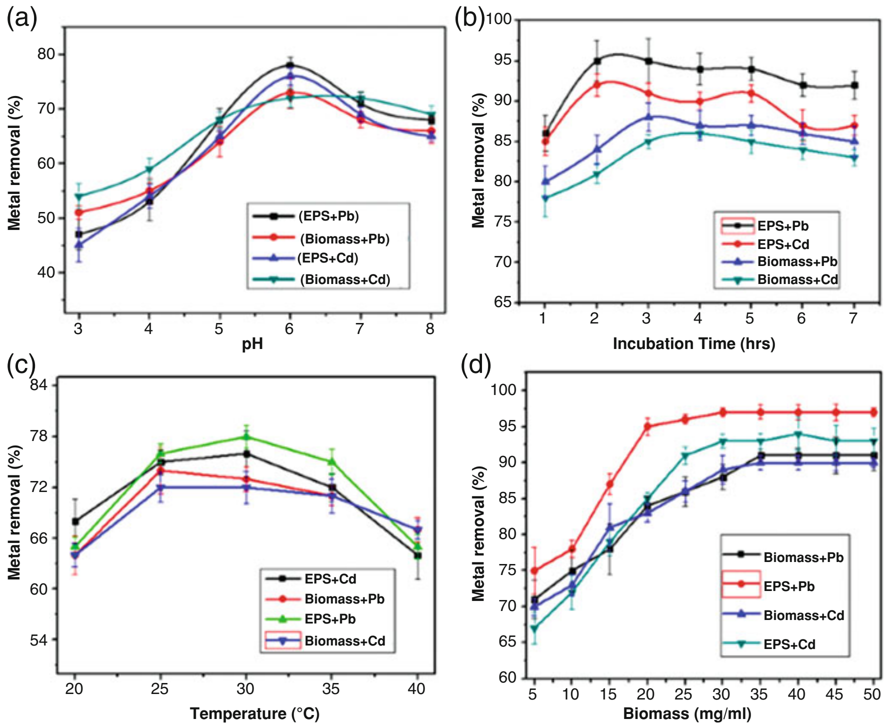

Fig. 8.5 Effect of pH (**a**) incubation time, (**b**) temperature, (**c**) biomass concentration, (**d**) biosorption of Pb (II), and Cd (II) onto biomass and expo-polysaccharides (EPS) of bioremediator fungi. (After Paria and Chakraborty 2017)

treated EPS sample, respectively. Major shift has been observed for **Pb**-treated **EPS** individual strong interaction of **Pb** with **C–O** bond (Paria et al. 2017) (Figs. 8.4, 8.5 and 8.6). The chemical characteristics of *Aspergillus penicillioides* are shown in Fig. 8.5. where the spectral features for fungus are well established, and the band assignments are represented. Additional information on phospholipids along with phosphodiesters, free phosphate, and monoester phosphate functional groups were observed near **1238** and **1082 cm^{-1}**, respectively.

Microbes are now being used as biological adsorbents to remove heavy metals from wastewater at low cost and in eco-friendly way (Bai and Abrahim 2003; Elizabeth and Anuradha 2000; Gadd 1990). The absorption of heavy metals by echisso polysaccharides (EPS) represents a metabolism-independent process and is driven by an array of interactions between metal cation and negative charges of acidic functional groups of **EPS** (Kim et al. 1996). Therefore, the studies conducted by Paria et al. 2017 have shown that the fungus *Aspergillus penicillioides*, strain **F1** was found to tolerate high concentration of **Cd(II)** and **Pb(II)** up to **1000 ppm** level. Both biomass and **EPS** have been able to remove aqueous **Pb(II)** and **Cd(II)** which have been optimized in batch culture process. Interestingly, **EPS** acting as the most

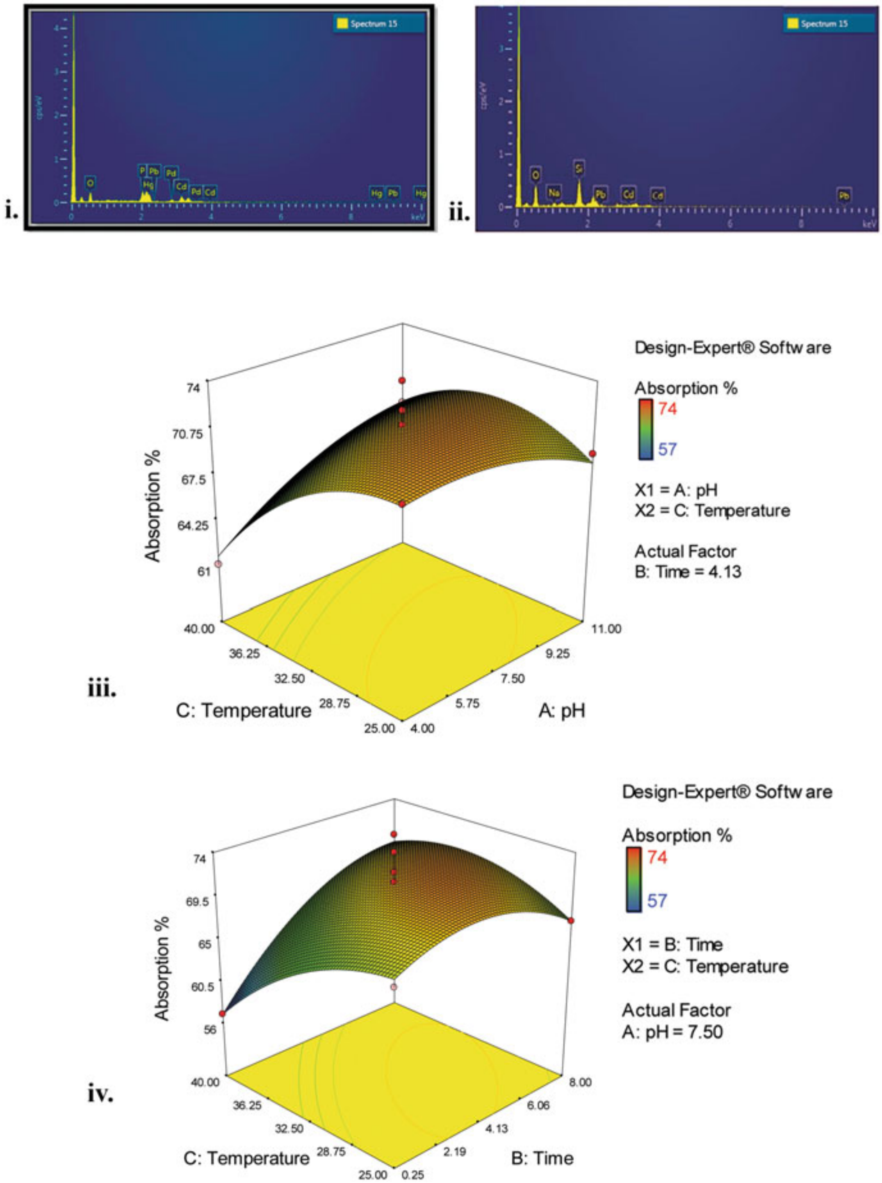

Fig. 8.6 Obtained EDEX spectra of F12 strain of fungal biomass. (After Paria and Chakraborty 2017)

efficient biochemical entities than biomass facilitate heavy metals bioaccumulation. The affinity of **EPS** was tended to be higher to **Pb(II)** than **Cd(II)** when both of them supplemented equally at mixed concentration. Such findings can explain the selective advantage of the strain **F12** for simultaneous removal efficiencies of **Pb (II)** and **Cd(II)** in aqueous system especially loaded with industrial discharge.

8.13.7 River Restoration Based on Rivers/Streams Hydrodynamics

Large river cut-off channels are currently considered as a high source of productivity and diversity in fluvial hydrosystems (Drago 1976; Holčík et al. 1981). This diversity results from **(i)** ecological succession occurring in both slow flowing and almost stagnant water bodies in contrast to the main river channel having higher current of water and **(ii)** episodic connections with the river during floods, which carry and import varieties of flora and fauna along with suspended materials (Schneider and Sharitz 1988; Nilsson et al. 1991).

Succession can be partially reset by these flood-mediated disturbances, enabling the co-occurrence and coexistence of different biotic components constituting the communities representing various successional stages (Bravard et al. 1986; Foeckler et al. 1991). Connell (1978) proposed the **intermediate disturbance hypothesis** which stated that disturbances with intermediate frequency and magnitude allow and facilitate such co-occurrence of fast-growing and competitive ruderal species, leading to higher richness and diversity of species. Such a pattern has been observed in wetlands. Different researchers across the world (Nilsson et al. 1991; Keddy 1983), where intermediate frequency of disturbances, resulted from some specialized modes of connectivities in between the wetlands and the rivers, support and maintain the lives of competitively weak and also rare species (Wisheu and Keddy 1989; Bornette and Large 1995).

Therefore, delineation of the effects of connectivity, between cut-off channels and a river, on aquatic plant diversity or rarity, helps proper developing in order to provide recommendations for the conservation of those species. The hypothesis stated that intermediate connectivity tended to allow inputs of propagules into the wetlands, without impeding their recruitment, which promotes high species richness. Conversely, high connectivity interrupt recruitment either by over-frequent flood scouring or by supplying nutrient-rich and turbid surface waters to the wetland, which in turn reduces species richness. In the same way, too low connectivity is supposed to decrease flood scouring and succession rejuvenation and trigger more competition to eliminate the less competitive species. This development coupled with almost retarded recruitment of new species by the import of propagules during floods result in decrease of species richness and the number of rare species.

8.13.8 River Restoration by Hydro-morphological Approach: Case Study from Europe

In order to achieve the goals of most of the river restoration efforts by the European Union (**EU**) by Water Framework Directive all over Europe in order to achieve **good ecological status** or **good ecological potential**, re-meandering, and widening, and the reconnection of rivers and floodplains was made. Such restoration activities mainly recorded the ecological consequences on the effects of hydro-morphological restoration on some species or taxa, instead of undertaking comprehensive investigations on species interactions within biotic community.

Comparison of the effects of restoration on different groups of organisms is scarce, but the available results generated out of all those studies imply that restoration activities often impose insignificant impacts, on benthic fauna, fish, and aquatic macrophytes, the reasons of which have appeared to become obscure. In order to address this question, an international team of scientists under the auspices of **RRFECM** (restoring rivers for effective catchment management) had undertaken research surveys for studying **20** eco-restored river stretches in ten European catchments and compared the research outcomes with the findings of nearby non-restored stretch of the same river (Hering et al. 2015). However, the possible cause is being thought that most of these research studies of the effect of restoration were undertaken within the very short river stretches which are insufficient to initiate geomorphic processes and their alterations so that biotic residents, mostly benthic fauna and fish do not face any disturbance. Different research studies have advocated on different perspectives of possible impacts of restoration programs such as Muhar et al. (2016) alongside providing background information on the study's set up and the individual restoration measures put forward recommendations for water management highlighting on the detailed results for the individual parameters and studied organisms: hydro-morphology (Poppe et al. 2016), aquatic macrophytes (Ecke et al. 2016), benthic invertebrates (Verdonschot et al. 2016), fish (Schmutz et al. 2016), floodplain vegetation (Göthe et al. 2016), riparian ground beetles (Januschke and Verdonschot 2016), food webs (Kupilas et al. 2016), and ecosystem services (Vermaat et al. 2016).

8.13.9 Long Term and Sustainable Restoration

The role of connectivity of channels long term and sustainable restoration of river takes into account fluvial ecodynamic processes within the rivers along with the adjacent floodplains, through an arrays of multitude of interactions between the different attributes of physical environment (morphology, flow, sediment, etc.) and the riverine ecosystem (EU Water Framework Directive 2000).

Various concepts pertaining to river morphology and ecology justify the fluvial systems being a hierarchical framework that integrates several unique geomorphic and ecological attributes in temporal and spatial scales. All these entities exist as a nested hierarchy which being as the structural components build up **hydraulic units** as the smallest level within the hierarchy to form the larger ones in a sequence such as **geomorphic units**, **river reaches**, and **landscape units** and, finally, to the level of catchment and then to an eco-region as the largest spatial scales.

These fluvial features are being depicted as physical templates that furnish the setting where all ecological processes operate and determine riverine coenoses. Giving more emphasis on the ecological functions and the resultant biocoenoses of these different spatial entities, aquatic ecologists use the terms as micro-, meso-, and macro habitats. A microhabitat, containing several hydraulic and physical factors such as depth, currents and velocity of flows, depth, properties of the sediments, and the types and extent of vegetation cover, is used by a species and the individuals belonging under it for specific biological need such as for foreaging, spawning, etc. Depending on the types of the taxa (fish, invertebrates, macrophytes, algae, etc.) and their different modes of life histories, the sizes of microhabitats may range from almost zero to a few meters. The mesohabitats exemplified by shallow riffles, deep pools, runs showing high flow velocities, or sediment bars and characterized by larger dimension in respect of an area (extend over an area of few square meters), **hydraulic** and **geomorphic units** denote discrete patches of a river channel characterized by similar physical attributes.

While microhabitats are used by individual organisms, in mesohabitats, several constituent aquatic species of aquatic biotic communities with their different stages in the life cycle with similar habitat requirements live (foraging, breeding, spawning sites for juveniles, and adults). A macrohabitat is the combination of several mesohabitats formed by certain hydro-morphological characteristics of the respective river or its branches. The abundance, distribution, and chances of migration of aquatic organisms are dependent on the longitudinal continuity and lateral hydrological connectivity within the microhabitat. The different ecological characteristics of the fluvial system along with floodplains and other habitats of biota experience the impact of hydro-morphological and ecological changes due to the influences and fluxes of such flows of water and sediments, from the reach or catchment scale.

8.14 Sediment Management Options: Prerequisite for Restoration

In order to undertake sediment management in river catchments, two options are given considerations: **(1)** structural and **(2)** nonstructural measures, which can be established on various river scales. Owing to large-scale land-use changes, several ecological perturbations within the river or in the river basin are resulted which are as follows:

1. Increased erosion because of intensive agricultural land use and massive deforestation (Walling and Bates 1990).
2. A decrease in the input of erodible soil surfaces helps developing another management option, especially to prevent clogging of bed sediments.

Structural activities on a patch scale (dumping and installation of gravels, boulders, or deadwood) create patches of habitats which supply necessary components and conditions for maintaining the required substratum quality (Hauer 2015). Structural components, such as boulders, by virtue of their shapes, sizes, constituents, and rigidity, have the advantages over other materials to provide sheltering habitats especially during high (scouring) flows in the wake zone accompanied by reduced flow velocities and bottom shear stress. Such changes also demonstrate local scale impacts on the capacity of rivers to transport sediments. River widening leads to stop river bed incision and consequently results in a disorder in sediment continuum and channel rectification. All such changes have considerable negative impacts on river biodiversity. Aquatic biota (macro-invertebrates, fish) in their different stages of life cycle have their own choices for different sediment characteristics which are being displayed by their morphological adaptations and eco-physiological adjustments with changing soil types. Thus, different eco-geological processes pertaining to the sediment dynamics on all river scales have appeared to become one of the most important issues for sustainable river management.

8.15 Roles of Food Web in the River Restoration

Food webs representing the flow of energy and matters through several of its constituent food chains certainly play an important role for sustaining rivers as ecosystems and maintaining associated aquatic and terrestrial communities by virtue of their functioning involving several of structural components. Therefore, much more attentions are being paid on understanding the food web dynamics in a river ecosystem and also explicitly considering food web-related baseline information in the process of restoring habitat structure successfully instead of attaching more emphasis on some targeted species overlooking important constrains on ecologically effective restoration. Three food web-related consequences have been identified that potentially hinder successful river restoration:

1. Ambiguity in knowing the habitat carrying capacity
2. Over-deposition and enrichment of chemicals and contaminants
3. Development of hybrid food webs because of the interaction of native and invasive species

Furthermore, considerations of such food web are required to deal broad temporal and spatial frameworks for understanding the consequences of altered nutrient, organic matter (energy), water quality parameters, flow patterns, mode of reconnection of critical habitats and their food webs, and restoration processes in the changing environments (Figs. 8.2 and 8.3).

8.16 The Riverine Restoration Strategies: Across Spatial Scales on Landscape

The functional and structural elements of river landscape are determined by the sediment regime, interwoven connecting system and adjoining landscapes of river flows (Wiens 2002). Rivers and their adjacent floodplains act as functionally interrelated systems, which are mutually dependent on each other through interlinking of processes and structures, by floods, habitat-forming and habitat-providing processes, nutrient retention and provision, etc. Alongside such lateral linkages, these landscapes mostly rely on some natural attributes (hydrological, bed load, vegetation regime) which in turn act as driving forces in its longitudinal dimension by way of up- and downstream interactions within the river system, catchment areas, and even in the higher scales of bio-geographical eco-region.

Superimposed on these patterns of **natural** interactions, some other natural are alterations, such as barriers, water diversions, impoundments, and land-use shifts, impose human-induced pressures at the river site both in the upstream and even downstream parts of the catchment. The chalking out of restoration strategies must require a deep understanding of underlying ground truth conditions, relationships, and ecological processes at the time/space scales support the functions and features (biotic and abiotic) of river landscapes.

8.16.1 Setting Goals and Benchmarks for River Restoration: The "Leitbild Concept"

Restoration ecology and practice revolve on future success of restoration paying due importance on the intricate relationships among different abiotic and biotic components of the concerned ecosystem. Initially, this idea called as **Leitbild concept** has been considered as benchmark for a normal ecological status of a river ecosystem which was instrumental for "**future vision**" in order to have proper evaluation and planning for restoration strategies, based on the **natural potential** of a river ecosystem without having any intervention from anthropogenic activities, otherwise designated as **human disturbances** characterized by unprecedented variation in ecological, economic, and sociopolitical factors (Kern 1992; Muhar 1996; Huges et al. 2000).

Another "**benchmark**" in terms of "**operable targets for the future development of rivers**" designated as "**operational Leitbild**" has been given emphasis in a methodological framework of river restoration and management strategy. This "**two-step approach**" propel the **Leitbild** process from visionary (with highest level of natural ecological health, cited as reference conditions to operational stages identified as good ecological health). Simultaneously, this method provides a future target with an objective and comparable benchmark for the appropriate assessment of the ecological status of water bodies by locating the deviation from this benchmark (WFD_)

8.17 A Multi-scale Hierarchical Framework: River Restoration and Management

A multi-scale, hierarchical framework, the **restoring rivers for effective catchment management (REFORM)**, have been designed and developed emphasizing hydro-morphology from catchment to reach and delineating regional river types based on valley confinement, platform, and bed material involving nested spatial units at catchment, landscape, segment, reach, and other smaller and finer geomorphic units for sustainable river management solutions. Quantified indicators at each spatial scale highlight **three groups of assessments**:

1. Contemporary indicators at reach and geomorphic unit scales serve to investigate ongoing processes, forms, and types of human pressures within each reach highlighting hydro-morphological function and alteration, including functional ability of the reach in respect of its type, function of riparian corridor, and hydro-morphological alteration followed by adjustment.
2. Indicators at catchment to segment scales monitor and record production process and delivery systems of water and sediment to reaches and the trend of their alterations by human pressure in the time scales of past to present so that an inventory of changes over space and time is constructed.
3. Indicators based on historical reach and geomorphic unit scale help framing the trajectory of reach-scale changes which can be used to understand the process of development of different types of river reaches, experiencing different human pressures on the environment in temporal and spatial scales.

River management often focuses on individual reaches of river networks, aiming at improving the potential of river systems to cater to the need of human beings by way of developing the morphology, sedimentary and vegetation structure, dynamism, and behavior of river reaches which depend not only on natural processes but also sustain the impact of human-mediated ecological changes both within the reach and wider catchment.

Such knowledge is required to relate both the current and past pressures and processes of human interventions. In response to this complexity, several researchers have developed many spatially hierarchical frameworks in order to serve a variety of scientific and management needs and also to strengthen understanding of the functioning of river corridors, catchments, and networks (Naiman et al. 1992; Kondolf et al. 2003). Many such frameworks incorporating formal classifications of spatial units such as river reaches or segments based on specific attributes are mentioned below:

1. Frissell et al. (1986) had developed the most comprehensive conceptual multi-scale framework for investigating streams and habitats by incorporating hydro-morphological processes, river geomorphology, and assemblages of vegetation at all spatial scales in order to highlight their influence on habitat. The roles of indicators along with form and process at spatial unit and scale are to develop understanding of the functioning of spatial units and the process linkages among units and scales.

2. Some of the frameworks mainly put stresses on hydro-morphological processes which shape and drive longitudinal and lateral connectivity within river networks and corridors, the assemblage and turnover of physical habitats along with their sedimentary profiles, and vegetational assemblages along with their associated biota with those habitats.
3. Such frameworks are of different categories based on their concepts, designs, mode of functioning, and geo-biological attributes such as:
   (**a**) Conceptual, providing a way of thinking about or structuring analyses of river systems and interpreting their processes, morphology, and function (Frissell et al. 1986; Habersack 2000; Fausch et al. 2002; Thorp et al. 2006; Beechie et al. 2010; McCluney et al. 2014)
   (**b**) Quantitative, generating one or more indices or classifications of spatial units that support assessment of river systems (Rosgen 1994; González del Tánago and García de Jalón 2004; Merovich et al. 2013; Rinaldi et al. 2013, 2015a)
   (**c**) Intermediate, generating relatively open-ended indices or classes that can be interpreted flexibly (Brierley and Fryirs 2005)
4. The frameworks, based on time scales and temporal changes, include dimension of each spatial scale pertaining to some specific approaches (Habersack 2000; Dollar et al. 2007), whereas other approaches incorporate historical analyses with an aim at tracking human intervention-mediated changes in spatial units through time at some spatial scales (Rosgen 1994; Montgomery and MacDonald 2002; Brierley and Fryirs 2005; Beechie et al. 2010; Rinaldi et al. 2013, 2015a).
5. Most of the frameworks incorporate characteristics for depicting the structure and function of spatial units and also provide specific indicators to assess the forms and processes of spatial units (Rosgen 1994; Montgomery and Buffington 1997, 1998; Montgomery and MacDonald 2002; Benda et al. 2004; Brierley and Fryirs 2005; Merovich et al. 2013; Rinaldi et al. 2013, 2015a).
6. Additionally, some of the frameworks include some unique indicators for evaluating the impacts of human pressures (Merovich et al. 2013; McCluney et al. 2014; Rinaldi et al. 2013, 2015a).
7. Finally, most frameworks are described based on their incorporated processes, but some process-based methods are developed where processes are inferred from forms and associations rather than being quantified by direct measurements.

This **REFORM** framework was developed emphasizing upon several novel properties, as mentioned below that make it convenient and suitable to river managers working in the environmental contexts and thereby to fulfill the objective of supporting sustainable river management and restoration (Gurnell et al. 2016).

1. Because the aim of the research was to develop a tool for use by river managers, the framework has been kept as simple to apply as was felt possible. It is a hydromorphological framework which includes relevant information on vegetation.
2. Reflecting the long history of human interventions on European rivers, the framework incorporates human pressures as well as natural processes and forms at all included spatial scales and gives them equal weighting.

3. The framework is open-ended to the extent that European member states can incorporate their own data sets, methods, and modeling tools, although specific methods have been proposed and fully described for consideration by member states.
4. The framework includes spatial units at region, catchment, landscape unit, segment, reach, geomorphic unit, hydraulic unit, and river element (patch of sediment, plant stand, etc.) scales.
5. The key scale of the framework is the river reach, since this is the scale at which rivers are most often assessed, managed, and rehabilitated.
6. A central and unique feature of the **REFORM** framework is that all reaches are classified into "**river types**" using clearly- defined, simple criteria. Different constituting elements of the framework function to enable understanding the naturalness or artificiality of different types of reaches along with the processes to which they are subjected and their morphodynamic behavior.

   This involves the assessment of the following:

   (i) The cascade of processes affecting reaches from catchment to reach scales.
   (ii) The degree to which reaches display characteristics at reach and finer scales that are indicative of "**natural**" function according to their type or of "artificiality"
   (iii) The ways in which reach morphology has changed or behaved through time after being triggered by the changes in processes and also by direct human interventions at catchment to reach scales

7. Indicators support the past and present behavior, form and function of river reaches and their riparian zones, patterns of water and sediment production, and delivery at catchment to reach scales, in response to human pressures from catchment to reach scales processes, and morphological responses at each spatial scale. The reach type being the key indicator can delineate spatial units and highlight processes, forms, and human pressures.
8. Space–time understanding of catchments and their river systems is developed from the indicators and provides a basis for estimating potential reach-scale adjustments to future changes across the spatial units (climate change, land cover change, introduction, or removal of channel reinforcement or structures).

Such analyses also help identifying the river type which has initially defined by simple rules corresponding to the river types that might function most effectively at a given location or whether a different type is more appropriate, so informing the design of any proposed restoration. The key scale is the reach scale, and the key indicator at this scale is the river type.

Twenty three (**23**) river types are defined using three criteria:

1. Valley confinement: confined, partly confined, and unconfined.
2. Platform: straight, sinuous, meandering, braiding, anabranching (defined using specific ranges of values of sinuosity, braiding, and anabranching indices).
3. Bed material: bedrock, colluvial, boulder cobble, gravel, sand, silt, clay. River types range from "**confined bedrock**" to "**unconfined, sand-silt,**

anabranching," with reaches with an artificial bed allocated to an "**artificial**" type. In addition, the river types are associated with floodplain types and the typical floodplain geomorphic units which form the product of the long-term dynamics of the river type (Gurnell et al. 2016).

8.17.1 Hydro-morphological Alteration and Adjustment in the Riverine Ecosystem

These can be explained by the following points (Gurnell et al. 2016):

First, the function/artificiality of riparian corridors assessed using indicators of the size, vegetation age structure, and sources and presence of large wood within the riparian corridor of the reach human pressures and the degree of disruption of longitudinal and lateral continuity.

Second, the degree and pathways in which the reach appears to be adjusting or behaving at present are assessed using indicators of the presence, extent and spatial pattern of relevant geomorphic units, and the sedimentary structure of bed and banks.

Third, past and present indicators at catchment, landscape unit, and segment scales are used to estimate past and present water production and delivery and river flow regime and also sediment production and delivery from the catchment and through the river network. Comparison of present and past values of these indicators helps quantifying the degree to which flow and sediment processes (land cover changes, dam construction, channel reinforcement, etc.) have changed through time and the likely causes of such changes.

Fourth, reach scale historical indicators are coupled with the contemporary reach scale indicators to reconstruct, as far as possible, the nature of morphological changes within a reach and the timing of those changes to indicate the changing behavior of the reach. For example, based on an analysis of historical maps and air photographs, an individual reach may show a trajectory of channel narrowing, widening, lateral migration, or a change in river type through time, or the reach may switch from one adjustment type to another.

Fifth, potential responses at the reach scale to future scenarios of change can be considered, usually focusing on reaches of different river type within particular segments or landscape units and using information on the way reaches of this type have adjusted in the past.

Furthermore, where reaches are heavily modified by human interventions, historical analyses of all reaches and consideration of future scenarios may contribute to identifying a more appropriate reach type that could guide rehabilitation or restoration designs. Therefore, the **REFORM** framework used in the European rivers can also be applied in the riverine landscapes in different parts of the world that have a similar, long history of human pressures (González del Tánago et al. 2015).

8.18 Integrated River Basin Management: Restoration on Social Context

The European Water Framework Directive (**WFD**; European Commission 2000) has put much emphasis as a prime issue in its water policy agenda for ensuring protection and restoration of the aquatic environment, especially for the river management. Global restoration efforts have been geared up in the sphere of river management in more sustainable manner by integrating policy and science to harmonize engineering, ecological, and social concerns. A number of management frameworks have been developed by undertaking continuous, separate, and parallel experiments during the last few decades in the form of **integrated river basin management (IRBM)** policies in order to achieve these goals. Most of the existing management lineages are required to converge on a broad-spectrum of commonness to ensure sustainable management of natural resources with a control over human activities in river basins following an integrated and interdisciplinary approach. The recent management programs put more stresses on the need to consider restoration and conservation activities in a social context.

8.18.1 Restoration of River Basins: Techno-Socio-Political Forces

Developmental projects framed by two perspectives of different magnitudes, e.g., engineering and socioeconomics, are supposed to provide short-term benefits in return of intensive investments in a few commercial sectors, such as intensive agriculture, transport, and other industries. Declining of the environmental qualities, mostly of soils and water of rivers along with other biotic communities of rivers, points out the lacunae of such narrow policies which often fail to achieve the target because of noninvolvement of all those factors and actors, the combined functional roles of which ensure the sustenance of river ecosystems and the human society over the long term (Pahl-Wostl et al. 2011; Sendzimir et al. 2008; Gleick 2003). Restoration efforts for the streams and rivers in a sustainable manner have increasingly reached to a broader context, giving due importance to socio-ecological system (SES) by integrating the social and cultural requirements (Wohl 2005).

8.18.2 Comprehensive Restoration Planning

In the attempt of undertaking restoration activities, the cumulative impacts of history should be provided with more emphasis as the system's resiliencies are required to be increased to sustain the impacts of multiple sources of the present and future environmental variation. Systems are required to adapt to varying and unpredictable forces even after the mitigation of the human impacts. This indicates that designing of the best restoration strategies incorporating novel and innovative inputs may not be able to achieve desired and anticipated outcomes, and this has pointed out that efforts must be oriented to adjust policies and practices with the progress of restoration process. Therefore, the central theme of restoration design involves a stepwise process which link up a series of logical working phases such as the assessment of the eco-geo-biology of river and catchment, selection of restoration goals, identification and prioritization of actions, designing of restoration-related projects, and development of program for monitoring restoration processes (Jungwirth et al. 2002; Roni et al. 2013). In the last few decades, considerable progress has been made in river restoration activities focusing on to the following:

1. More attention has been provided to stakeholder participation by developing integrative approaches to planning, implementation, monitoring, and adaptive revision of policies and practices.
2. Categorization of the restoration measures and their dimensions is made before execution and implementation.
3. Increasing awareness of the importance of monitoring programs. The success of habitat restoration in channelized rivers is constrained by several factors which are mentioned below:

   (**i**) The non-availability of the space lateral to the river channel because of intensive inland uses coupled with the encroachment of river basin for the purpose of human settlement.
   (**ii**) Altered flow regimes, coupled with truncated sediment supply, cause hindrance to the recovery of the original river-type-specific fluvial processes and dynamics.
   (**iii**) Lack of integrative solution of the basin-wide sediment management to resist further bed degradation and to enhance habitat diversity.
   (**iv**) Development of several natural and artificial migration barriers (weirs, impoundments, ramps) limiting the recolonization of living biota through interrupted longitudinal connectivity.

Besides, the existing fluvial systems are constrained with several natural and anthropogenic pressures which are difficult to manage solely by morphological habitat restoration (Schinegger et al. 2012; Tockner et al. 2010; Hering et al. 2015) which has necessitated to undertake for more intensive and integrative basin-wide approach that extend beyond fluvial morphology by way of involving all functional aspects of river systems.

Summing up, it can be inferred that to develop successful as well as sustainable short- and long-term restoration strategies of river, a clear and transparent understanding of the cause and effect relationships between the natural physical processes operating in the river systems and altered ecological developments due to human activities coupled with identification and application of suitable ecological factor are required (Frissell and Ralph 1998).

8.18.3 Restoration and Legal Framework: Dependence on Socioeconomic Profiles

One step toward environmental restoration will be to rework on the legal basis for environmental protection that will be the foundation of an effective environmental policy. But to do this, under governments that still focus on economic development through resource utilization and provide little incentive for efficiency and concern for the environment is at best difficult. The institutions of government may have to change some more before any comprehensive and effective environmental legislation can be enacted and begin to have any impact. Clearly this is a slow political and social process. But it is not too early to start or keep up the pressure for such changes. It is also not too early to stimulate research and development activities on all aspects affecting the environment and ecosystem restoration and enhancement, from ways of reducing the production and increasing the recycling of wastes in industry and agriculture, to the development of innovative and cost-effective waste treatment schemes, to methods for assessing the final physical as well as economic impact of those wastes in and on the environment.

Identification of appropriate, and certainly improved, policies and institutions dealing with environmental issues is required based on relevant research studies. For example, the end result of all these recent political and economic changes in developing countries ends up with some mix of centrally planned and market-driven economies, in order to explore the ways and means for environmental cleanup and preservation.

8.19 Multiple Purpose Integrated, Interdisciplinary Restoration Planning

Multiple purpose water resources planning and development are based on the realization that engineering facilities can store, distribute, and control the quantity and quality of water over time and space. These facilities can serve a variety of purposes, e.g., municipal, industrial and agricultural water supply, hydropower, navigation and transport of cargo, wastewater transport and assimilation, quality and aquatic habitat enhancement, and recreation. Integrated planning recognizes the possible interdependencies among various structural and nonstructural components of a basin-wide or regional land and water resource system. It recognizes interdependencies between the quantity and quality of water of both surface and groundwaters.

Integrated planning insures that the design and operation of existing components, and of any proposed component or project to be implemented in the future, takes into account these interdependencies and thus contributes to the performance of the entire system rather than to just that of a portion of the system. Multidisciplinary planning recognizes the limitation of individuals trained in any single discipline to adequately plan, design, develop, and manage, by themselves, a system as complex as a water resource system that affects so many organisms and organizations, and individuals and institutions, over time and space, in so many different ways.

River system restoration is largely motivated by the adverse economic as well as environmental impacts of degraded water bodies and associated land areas. Much of this degradation has often been due to the past land and water development where the objectives have been to straighten water courses, drain land, protect from floods, and hence control the flow and storage of water. The result has often increased erosion and sediment loads, decreased water quality and more frequent and more severe flooding, reduced populations and diversity of wildlife, and decreased recreational values. These adverse impacts are among the main reasons for returning streams, lakes, and their watersheds to a more natural and sustainable state. To decide just what mix of structural and nonstructural measures will achieve the objectives of any restoration project, one must be able to predict the impacts of any alternative plan or operating policy. In many cases, such predictions are not able to be made with any degree of certainty.

Therefore, an integrative approach is the demand of the time which rests on the principle an adaptive approach must be taken that one action and monitoring be adapted and executed followed by other and more monitoring and applications integrating several fields of applied research such as ecology, geo-hydrology, hydro-dynamics, biodiversity, engineering, economics, sociology, and so forth. However, step-by-step approach have appeared to be most suitable. One of the first steps in the planning of any restoration program is to identify the area to be restored and to begin to understand the interrelationships and interactions among the water- and land-based ecologic (including economic) components and habitats of that area.

The ecological components must be examined at several spatial scales to define adequately the food chain required by aquatic and terrestrial organisms. Rivers and streams are integrated flowing systems that create and maintain aquatic habitats on and below their wetted boundaries. In a drainage basin, the flow habitats are nested within one another at smaller and smaller scales, from the channel segment, to the reach, to the sub-reach, and to the boundary layer and substrate flow. Successful stream rehabilitation of enhancement designs must often predict hydraulic conditions in all levels of habitat, but the determination of designs to achieve specific fluvial processes, site-specific hydraulics, and aquatic organisms is often not possible, particularly at the lower scale levels (Tockner and Standford, 2002; Tockner et al. 1998, 1999, 2000; Lemke et al. 2017a ,2017b, 2017c, 2017d; Kupilas et al. 2016).

8.20 Watershed and Water Quality Management: A Step Toward Restoration

Watershed management today has taken on a rather specific meaning in the **USA**. It refers to the prevention and control of both point and non-point pollutants and the need for a comprehensive land and water management approach in order to do this effectively and efficiently. Historically water pollution control in the **USA** has been based on permits and regulations or restrictions on the amount of point discharges of various constituents. This approach has focused on individual sources rather than an overall watershed and water receiving system. As discharges from the point source pollutants were reduced, mainly through investments in wastewater treatment facilities, it became increasingly clear that the non-point pollutant loads were substantial, and they also needed to be reduced.

Thus, the current **US Environmental Protection Agency's** response is to develop and implement a national watershed protection strategy. This strategy addresses the integration of existing water pollution control functions into a broader watershed context. The attempt is to achieve cost-effectiveness by providing a flexible means of integrating diverse structural and nonstructural pollution prevention and control activities. The goal is to achieve reductions in the total pollutant loadings via land and air to natural water bodies in a cost-effective manner.

8.21 Pollution Prevention and Control: Restoration Alternatives

Options for the control of non-point pollutant runoff from urban and agricultural areas in watersheds include structural and nonstructural options. Structural **best management practices (BMPs)** typically involve treatment of storm water runoff, infiltration, filtration, and detention. Traditional infiltration practices include infiltration trenches and basins, dry wells, and porous pavements. Retention basins include bio-retention basins where vegetation helps treat first flush runoff waters.

Traditional filtration practices include filter strips, grassed areas, and sand filters. These treat sheet flow by using vegetation or sand to filter and settle particles and have been found to be very effective in the short term with shallow flow. Peat-sand filters are an innovative practice that combines the high phosphorus and biochemical oxygen demand removal capabilities of peat with a nutrient-removing grass cover crop and a subsurface sand layer to achieve high pollutant removal efficiencies.

Detention temporarily impoundments to control runoff rates and to allow settling of suspended solids and associated pollutants; detention ponds and wet ponds are examples. Constructed wetlands are engineered systems designed to simulate natural wetlands, combining infiltration, filtration, and detention with vegetative uptake to treat runoff.

Constructed wetlands for wastewater and storm water treatment provide, in appropriate climates, a low-cost option involving natural systems and processes that often become a part of restoration projects. In the **USA**, the two most common types of constructed wetlands in use are freewater surface and submerged flow systems. The concept pertaining to the development of the nomenclature of free water surface wetlands has emerged imitating natural wetlands. They usually have soil (gravel, sand, silt, clay, or peat) bottoms, emergent vegetation, and water exposed to the atmosphere. The vegetation is planted in the shallow basins or channels, with relatively low-water depth. Alternatively, submerged flow wetlands maintain the water or wastewater level below the surface of a soil media of rocks and gravel with no free opening to the atmosphere.

Nonstructural practices include integrated pest management, street sweeping, and waste oil collection. Nonstructural measures usually involve reduction of the pollutants at their sources before being transported by runoff. Agricultural non-point pollution results from soil erosion and the land application and subsequent runoff of animal wastes, fertilizers, pesticides, and herbicides. Saline drainage waters from irrigation sites can also add to the non-point pollutant loads. Management of agricultural lands may have direct impacts on ecosystem habitats, as well as indirect impacts due to the quantity and quality of the runoff. Measures to reduce the quantity of agricultural runoff include conservation tillage, contouring plowing and plantings, terracing, vegetative filter strips, and the use of cover crops. Measures to reduce pollutant concentrations in agricultural runoff include nutrient, pesticide and herbicide management, integrated pest management, and chemical use control and hazardous waste collection.

8.22 Effects of Hydro-morphological River Restoration: Case Studies from Europe

All over Europe, restoration activities along the river stretches have been undertaken to achieve **"good ecological status" or "good ecological potential,"** in tune with the targets of the **European Union's Water Framework Directive** (**WFD**). Hydro-morphological restoration being the most acceptable method involves re-meandering, widening, and the reconnection of river and floodplain. Although several studies have been made to record the effects of hydro-morphological restoration on individual species or taxa, comprehensive investigations with an aim at comparing the effects of restoration on different groups of organisms are very limited.

All these research information have pointed out on the very negligible impacts on benthic fauna, fish, and aquatic macrophytes which are supposed to be due the observations were made only on to very short river stretches which are being restored. These small stretches of rivers might not be sufficient for the initiation of geomorphic processes and also to support good populations of aquatic species. Many other research studies have reported on the detailed results pertaining to the impact of individual parameter on the different groups of organisms which are:

(**i**) Hydro-morphology (Poppe et al. 2016)
(**ii**) Aquatic macrophytes (Ecke et al. 2016)
(**iii**) Benthic invertebrates (Verdonschot et al. 2016)
(**iv**) Fish (Schmutz et al. 2016)
(**v**) Floodplain vegetation (Göthe et al. 2016)

(**vi**) Riparian ground beetles (Januschke and Verdonschot 2016)
(**vii**) Food webs (Kupilas et al. 2016)
(**viii**) Ecosystem services (Vermaat et al. 2016)

8.23 River Floodplain Restoration: A Case Study from the Emiquon Preserve in Illinois River System, USA

Throughout the period of evolution of human civilizations, large rivers and their floodplains have been used nonjudiciously for providing benefits to human beings which have resulted in the alterations of the ecology of those rivers with so many negative ecological consequences (loss of biodiversity, destruction of habitats, enhancement of the concentration of toxic substances, spreading of diseases, etc.) for millennia (Welcomme 1985; Bayley 1995; Dynesius and Nilsson 1994; Sparks 1995; Tockner and Stanford 2002).

Understanding of the restoration success of the floodplain restoration at the Emiquon Preserve, a part of the Illinois River system, **USA**, and the respective ecological consequences in respect of the sustenance of the aquatic and terrestrial communities associated with the river–floodplain system have highlighted the roles of flood attenuation, sediment capture, and nutrient processing. This also takes into consideration of improved governance for coordinated management of the system (TNC 1998, 2000) that would provide ecological, social, and economic benefits within the Illinois River system (Reuter et al. 2005). Several noteworthy aspects of the Emiquon Preserve restoration case study are as follows:

First, well-coordinated efforts were made to identify the appropriate planning process prior to undertaking restoration involving external experts and stakeholders that resulted in the development of a guidance framework to be used for monitoring and evaluating restoration status in comparison with the early restoration success (Lemke et al. 2017a, b, c, d).

Second, the restoration and monitoring were designed to contribute to better documentation of the feasibility and sustainability of ecological restoration in highly altered floodplain–river systems (Suding et al. 2004; Choi et al. 2008; Hobbs and Cramer 2008; Jackson and Pringle 2010). The major guidelines generated out of this action ecological research on the restoration and conservation programs undertaken on a large river ecosystems should include the following:

1. A detailed reviewing of the scientific and historical context of the river and regions of their flows
2. With a description of restoration progress and also to highlight the significance for large river restoration ecology
3. Major impacts of human development
4. The steps of recovery and restoration

8.23.1 Time Scale Analysis of Restoration Process: Emiquon Preserve, in Illinois River System, USA

8.23.1.1 Period 1 (Prehistoric-1900): Period of Minor Human Disturbance

The key events in the scientific and historical context of restoration process in the Illinois River and Region, located in the in northern **Illinois**, **USA** with the draining potential of **73,038 km^2** as it flows **439 km** to the Mississippi River (Starrett 1972). It possesses broad floodplain experiencing seasonal flood pulse and supports the lives of prehistoric populations of Native Americans primarily between **800** and **1400 AD** (Esarey 1993). Impacts out of harvesting of natural resources for food, fuel, gardening, and farming and for construction purposes and also intentional burning of prairies and some forests of these early civilizations on the river system have not been found to be at significant level, the information of which trigger and direct the different restoration activities (Wiant and Berkson 2004).

8.23.1.2 Period 2 (1901–1971): Human Development and Major Impacts to the Illinois River

Pioneering and innovative research studies which were undertaken during the period spanning from **1901** to **1971** had focused more on the natural river system which underwent threats out of several developmental activities especially by changing land uses. Such development-mediated river pollution in the upper reach had resulted in extirpation of all bottom-dwelling invertebrates first and subsequently fishes (Forbes and Richardson 1913; Thompson 1928; Richardson 1928) and also settlement and proliferation of more pollution-tolerant forms (tubificid worms and midge larvae by outcompeting and replacing of the sensitive clean water species (mayflies and a variety of snails).

Water diversion for continuous few years regulate the volume and the depth of the water in the aquatic habitat, which soon resulted to long-term degradation through the eroded shorelines, uprooted aquatic plants, suspended soft fluvial sediments, sediment compaction, moist soil revegetation, and mineral processing (Forbes and Richardson 1919; Starrett 1972; Bellrose et al. 1983; Sparks et al. 2016). Jenkins et al. (1950) reported that levee construction resulted in a marked increase of the height of flood crests (**3 meters**) in between **1904** and **1943**. Subsoil drainage associated with the intensification of agriculture and channelization of the tributaries also aggravated the ecological state by enhancing the intensity of erosion along with accelerated flows of water loaded with sediment to the river.

8.23.1.3 Origin of Flood Pulse Concept (FPC)

8.23.1.3.1 The Flood Pulse Concept (FPC)

The **FPC** proposed first by Junk et al. (1989) was primarily based on research in the Central Amazon floodplains, where a range of ecosystem components including chemical cycles (Kern and Darwich 1997; Wassmann and Martius 1997; Weber 1997), flora (Junk and Piedade 1997; Ferreira and Stohlgren 1999; Wittmann et al. 2011), and fauna (Petry et al. 2003; Lobón-Cerviá et al. 2015) were analyzed over the last few decades. The FPC recognizes the seasonal pattern of supply and delivery of river water enjoying definite regularity, intensity, and predictability onto floodplains as the main driver of biogeochemical cycles, habitat characteristics, and species richness in large river floodplains (Junk et al. 1989). Indeed, recent research has quantified and demonstrated that flood predictability (or rhythmicity) across river systems determines aquatic species richness and plant productivity (Jardine et al. 2015) allowing and accelerating adaptabilities of highly diverse biota to survive in the changing ecological condition maintaining their genetic and species diversity in the floodplain ecosystem. A comprehensive river ecology theory explaining the flood pulse patterns of the Illinois River was proposed at frag end of the twentieth century as the **Flood pulse Concept** (Junk et al. 1989) and recently modified as **The Flood pulse Advantage** (Bayley 1991) which mainly have highlighted the significance of the flood pulse in determining the ecology of the large rivers, especially by facilitating and accelerating the high system-level biological productivity. Since 1992, the **Illinois River system** has been designated as the restored river ecosystem having proper ecosystem function which are in tune with criteria for becoming an ecologically healthy river and with its floodplain (National Research Council 1992). Initiation of habitat and floodplain restoration within the river system require primary research information of all the system-level impacts that contributed to the eco-degradation of the system over time. The sources for all these impacts have been highlighted by Jackson and Pringle 2010; Guida et al. 2016; Sparks et al. 2016; Lemke et al. 2017a which are as follows:

1. Leveed floodplains
2. Agriculture and urbanization
3. Increased flood flashiness
4. Increased river flows from diversion
5. Unnaturally high river water levels
6. Invasive species
7. Higher loads of sediment, contaminants, and nutrients

8.23.1.4 Restoration and Major Eco-Climatic Variables: Conserving Working Hypothesis

Among the myriad of considerations, which are required for long-term, and large-scale restoration process, some major ones include hydrology, biota, and involvement of stakeholders. Prior to restoration in Emiquon water reserve, in the Illinois River in Northern Illinois, **USA**, drainage of the site through water pumping was discontinued, and the resulted rise of the water levels were primarily due to direct precipitation. During the time period between **2008** and **2009**, exceptionally heavy rainfall rapidly increased water volume and surface area within the reserve (Angel 2010). Evaporation during a moderate summer drought drastically reduced the water level that was followed by a modest increase of water level during the consequent spring.

Restoration of the habitats of biological communities and thereby promoting the biodiversity enrichment were accomplished by afforestation with the diverse natural flora which help suppress invasive species through biotic resistance followed, fish stocking, which in turn help natural regeneration, and recolonization. In the course of such restoration, related activities for the Emiquon restoration the **Conservancy's Working Hypothesis** emerged which states that a managed reconnection tends to facilitate the re-establishment of the natural hydrological dynamics that to a certain extent mimics the historic flood pulse (Reuter et al. 2005). The **flood pulse concept** puts more stresses on timing, magnitude, and duration of the river flood pulse that drive to result higher biological diversity and recovery of ecosystem health.

8.23.1.4.1 Biotic Community-Level Responses Towards Restoration Process

Several intensive studies by different researchers on river and floodplain restorations at different parts of the world have revealed different modes of ecological responses depicted by different groups of organisms such as microorganisms (Lemke et al. 2017b); vegetation (Hine et al. 2016), fish (Van Middlesworth et al. 2016a, b), and water birds (Hagy et al. 2016a, b). The research outcomes from the studies of Lemke et al. (2017b) have shown the changing patterns of large river system and intensity of responses displayed by microbial communities, based on which member populations of microbial communities were categorized as rapid and slow responders. Hine et al. (2016) from a long-term studies have reported that accounted for an eightfold increase of vegetation both in respect of density and the extent of coverage by natural regeneration process through a period spanning from **2007** to **2013** at Thompson and Flag Lakes where floating-leaved and submersed aquatic vegetation (about **44%**), and persistent emergent vegetation (**21%**) accounted as the dominant vegetation in the wetland habitat. The flooding in Emiquon Preserve lake basins revealed the positive responses of fish community which displayed higher abundance and production (Van Middlesworth et al. 2016a). A comprehensive long-term study to measure the mode of distribution and behavior of migratory water birds across a gradient of disturbance in a wetland sanctuary have shown their efficacy on the water environment at spatial and temporal scales. The diversity and density of avian taxa were found to be very less in the zones of exclusion of water birds near human disturbances frequently visited by hunters and other users (Hagy et al. 2016b).

8.23.1.4.2 Responses from Ecosystem Processes Towards Restoration

Some case studies focusing not only on ecosystem processes but on some other noted ecological parameters, such as on soil organic carbon so that a comparison can be made in between this parameter being a major determinant soil environment to other key ecological attributes and indicators which in turn can justify the significance of the storage of soil organic carbon as an indicator of restoration success (Chen et al. 2017). The connections between the river flood pulse to the floodplain have been accepted as the most important factor regulating the ecology of the river system, but the designing of the proper river management strategies providing due importance to the mode of operation, stepwise execution, costs, and benefit outcomes of the river to floodplain connection is still in its infancy because of the lack of transparency and knowledge.

The researchers have monitored the short-term effects of these flood disturbances on water quality, bacteria, zooplankton, plants, fishes, and birds during minor floods and major floods at Emiquon and Merwin river floodplain systems, respectively, and arrived at a conclusion that major flooding markedly changed the microbial and invertebrate communities, while only some erratic changes were identified from minor flooding (Sparks et al. 2016). Sparks et al. (2016) have studied the Emiquon river floodplain systems to understand its potential to become eco-restored in the future because of withstanding and sustaining the impacts of the water loaded with sediment, contaminants, nutrients, and also the harmful effects of the invasive species which all together usually contribute to cause unacceptable degradation of the aquatic ecosystem (Lemke et al. 2017a, b).

8.24 Advancing River Restoration and Management

The need and necessities of river restoration and management have emerged enormously during the recent decades, driven largely by increased recognition of the ecological values, and ecosystem services derived from the river functions. Many conventional river management techniques, emphasizing hard structural controls, have proven difficult to maintain over time, and often caused degradation of river environment. This has necessitated to undertake more sustainable and holistic river management with an object to view the **problem** at a larger catchment scale involving the application of tools from diverse fields of science and technology.

Success often hinges on understanding sometimes complex interactions among physical, ecological, and social processes. Therefore, an interdisciplinary approach toward conversation, testing, and refinement of existing scientific theories, designing of future planning for the evaluation of the best options, and proper understanding are required for an effective river restoration and management. All these steps are expected to reduce uncertainties leading to separate nature and culture which together influence and direct human actions. It also implies that scientists should emphasize on better communications between managers and practitioners, in order to percolate new insights generated from the research-based observations to the environmental managers, for the proper implementation of the projects in tune with the desired research directions.

The series provides a forum for "**integrative sciences**" to improve rivers. It highlights innovative approaches, from the underlying science, concepts, methodologies, new technologies, and new practices, to help managers and scientists alike for the improvement of our understanding of river processes with an aim to restore fluvial resources ensuring for more harmonious coexistence of humans with their fluvial environment.

8.25 Key Steps for Planning and Implementing Restoration

The subject "**restoration economy**" (Cunningham 2002) has been the recent development for accounting and assessment of cost benefit involvement toward restoration planning and development and functioning of numerous watershed councils, river trusts, and other agencies with restoration practitioners following systematic approach for planning restoration projects throughout a watershed or basin. Deviation from well-designed and economically planned restoration efforts has resulted in a number of failures or incomplete fulfillment of their objectives despite large financial investment. Major causes leading to such failure of a restoration program or project include the following:

1. Not focusing on the root causes of habitat or water quality degradation
2. Not recognizing upstream processes or downstream barriers to connectivity
3. Inappropriate uses of common techniques (one size fits all)
4. An inconsistent approach for prioritizing projects
5. Improper planning and developing of the project.
6. Non-availability of substantial support from public and private organizations
7. Inadequate monitoring to determine project effectiveness

In order to overcome these challenges and problems, several logical steps important for developing a successful restoration program or project are to be followed. These steps are the ways and means for improving the design and execution of stream and watershed restoration plans, watershed processes, and process-based restoration; assessment of watershed conditions and identification of restoration needs; selection of appropriate restoration actions to address restoration needs; selection of a prioritization strategy for prioritizing actions; proper planning and implementation of projects; and development of a monitoring and evaluation programs.

In addition, the socioeconomic and political aspects need to be incorporated throughout the planning and design process. Simultaneously, research-based baseline information are to be generated not only to identify the root causes of habitat and ecosystem degradation but also to take necessary steps for their management (Sear 1994; Roni et al. 2002; Beechie et al. 2010).

8.26 Watershed Processes, Human Impacts, and Process-Based Restoration

Effective planning, design, and implementation of river restoration efforts require an understanding of how watershed processes drive the structure and functions of riverine ecosystems, as well as how those processes support an array of ecosystem services. The term "**watershed process**" generally refers to movements of landscape or ecosystem components into and through river systems, which are typically measured as rates (Beechie and Bolton 1999). Although a number of processes operating within the watershed have appeared to be similar, minute and detailed analysis reveal their differences. For example, erosion in the river basin is a process that moves sediment from the basins to river channels, while sediment transport processes move sediment through stream and river channels from the upstream to downstream. Erosion is measured in units of mass/area/time, whereas sediment transport is commonly measured in units of mass and time.

Similarly, instead of referring the terms geo-morphological or hydrological processes, a wide range of geo-eco-biological processes are in force to justify the dynamic nature of riverine hydrodynamics including erosion and sediment transport, storage and routing of water, growth, diversity and successional processes of plants, movement, spiralling of nutrients, flows of energy, trophic interactions, and population dynamics. Understanding these processes and relationships between them is critical to the success of river restoration programs. These driving processes influence states and dynamics of biological communities through a sequence of cause–effect linkages that connect watershed processes to habitat conditions and habitat conditions to biota. Humans alter watershed processes in many ways, leading to changes in habitat conditions, food webs, and biological communities (Allan 2004).

Process-based restoration focuses on correcting anthropogenic disruptions to driving processes, thereby leading to recovery of habitats and biota (Sear 1994; Beechie and Bolton 1999). In the successful restoration processes, organisms with their are considered to be the habitats have appeared to be most important for achieving ecosystem recovery, by correcting ecosystem degradation and also by reintroducing key stone species, flagship species and native species in order to drive out the non-native species, and also to improve poor water quality (Karr 2006).

8.27 The Hierarchical Structure of Watersheds and Riverine Ecosystems

Different physical, chemical, and biological processes operating across a wide range of space- and time scales within and outside of river flows determine physical and biological features of riverine ecosystems. These processes also regulate the arrangement of channel and habitat types across the riverine landscape, such as reach-scale channel types, or pool and riffle units at smaller scales (Frissell et al. 1986; Fausch et al. 2002; Allan 2004). Community composition and interactions of riparian or aquatic species and their ecological niche and habitat preferences also control the biological processes (Beechie et al. 2008; Naiman et al. 2010). The formation of larger channels starting from the headwaters to lower rivers because of coalescing the small streams results the geo-ecological characteristics of habitats after being determined by six main variables: channel slope, valley confinement, discharge, sediment supply and size, bank strength, and vegetational support.

8.28 Process-Based Restoration

The concept of process-based river restoration has gained momentum in recent years, which put stress more on holistic restoration efforts and identification of root causes of ecosystem degradation and restoration of river ecosystems in a more cost-effective manner (Beechie and Bolton 1999; Brierley et al. 2002; Wohl et al. 2005; Palmer and Allan 2006; Kondolf et al. 2006).

The prime objective of process-based restoration is to "**re-establish normal paces, intensities and magnitudes of natural ecosystem processes (physical, chemical, and biological) that create and sustain river and floodplain ecosystems**" (Beechie et al. 2010). To meet this objective, **two primary needs** are to be satisfied:

1. To ensure that restoration plans and actions address root causes of degradation rather than symptoms
2. To support sustainable restoration that does not require repeated maintenance or intervention to achieve restoration objectives

While complete restoration processes is not always possible, it is important to recognize this as a goal during restoration planning and implementation. A focus on restoring processes to the fullest extent possible will guide restoration actions toward those that are most likely to succeed and ultimately reduce restoration costs over the long term. However, where socioeconomic constraints limit restoration actions to habitat improvement or construction, incorporating a process understanding into the design of individual restoration plans is also critical to improving the effectiveness of river restoration efforts that has necessitated to design effective restoration with a clear understanding of processes such as sediment transport, channel migration, or riparian functions and alterations of such processes by human activities.

8.28.1 Process-Based Principles for Restoration

Process-based restoration is guided by four basic principles (Beechie et al. 2010):

1. **Identify** and address the causative factors leading to the habitat and ecosystem change
2. **Tailor** restoration actions giving due importance to local potential
3. **Target** the scale of restoration in tune with the prevailing physical and biological processes
4. **Define** clearly the prospective outcomes, including recovery time

The purposes of these principles are to ensure that restoration actions are effective over the long term and to allow river ecosystems to respond to future climate change or other stochastic processes without continual human intervention. Such actions also accommodate natural spatial variation in habitat and ecosystem attributes and functions, as well as annual variation in storms and floods that are important to the creation and maintenance of habitat structure in river ecosystems. Each of the four principles has a specific purpose in guiding effective restoration. The core principle is to address root causes of degradation so that restoration is sustained and built structures are not overwhelmed by unrepaired processes (Beechie and Bolton 1999).

The second principle guides restoration designs and techniques to be consistent with local physical and biological potential, which is controlled by the landscape template as well as watershed processes where the **local potential is considered as same of that natural potential** (Kern 1992). Besides, it is needed to explore the possibility to bring the disturbed segments of rivers to natural or near-natural conditions as per feasible adopting most effective restoration actions.

However, where certain human constraints will not be removed (a large dam or a city on the floodplain), the definition of local potential must acknowledge those constraints. The conventional focus of the restoration of river and streams along with their floodplains has been on small actions in small streams (Bernhardt et al. 2005), but restoration efforts in the past decade have progressively increased in both scale and scope. Moreover, many years of emphasis on watershed analyses in river management planning have shown that watershed-scale problems require watershed-scale solutions, whereas reach-scale problems can be addressed locally.

Hence, the third principle guides restoration planners to explicitly identify the correct scale for restoration and to press for restoration actions that are of sufficient magnitude to successfully restore or rehabilitate river ecosystems. The fourth principle guides restoration planners to set realistic expectations for both the restoration outcome and the time required to achieve that outcome (Beechie et al. 2000; Brierley et al. 2002; Pollock et al. 2007). In part, this principle has the aim of forcing recognition that many restoration actions have limited benefit or long recovery time, whereas other projects have large benefits or short recovery time. Realistic predicted outcomes for restoration actions serve as the purpose of maintaining appropriate expectations for the magnitude and pace of ecosystem recovery.

Such predictions based on ground truth research information help avoid giving policy makers, funders, and managers a false expectation of drastic and rapid ecosystem recovery of the ecode-graded environment. Together these four principles aim to restore the dynamics of rivers, guide the design of restoration actions to restore process regimes rather than states, and produce variability in conditions rather than uniformity (Brierley et al. 2002; Beechie et al. 2010). For example, most of the research-based actions undertaken for river restoration processes should dissociate human interventions on those processes (levee removal to allow channel migration or removal of dams to restore movement of water, sediment, and biota), in order to maintain natural rhythm in ecological processes to drive habitat formation and ecosystem function. By contrast, actions that partially restore processes do not fully remove human influences but attempt to restore key attributes of natural processes.

8.28.2 Applying the Principles to Restoration

As complete restoration of riverine processes and their associated watersheds is rarely possible, attempt is usually made to undertake river restoration by employing a suite of restoration strategies ranging from fully restoring processes to habitat creation efforts by artificially constructing habitat as a substitute of natural ones. Most restoration approaches include three different aspects (Beechie et al. 2010):

1. Full restoration of processes (restoration)
2. Partial restoration of processes (rehabilitation)
3. Habitat creation or improvement (enhancement)

Full restoration actions include restoration of habitat-forming processes, and partial restoration actions ensure only restoration of selected ecosystem processes and functions, whereas habitat creation actions aim at building habitat rather than tackling the root causes of degradation (Cairns and Pollock 1988). Full and partial processes involved in restoration actions can use all of four of these process-based principles to direct actions toward success and sustainability.

By contrast, habitat creation, such as excavating a side channel, does not address the causal mechanism of degradation (**Principle 1**). Nevertheless, the remaining principles can be applied to ensure that actions are suited to the site potential (**Principle 2**), at an appropriate scale (**Principle 3**), and have clearly stated expected outcomes including recovery time and longevity (**Principle 4**).

Restoration actions that achieve this objective may fall into any of the three restoration categories.

The first strategy, being the simplest and quickest option, is a habitat creation strategy that relies mainly on the local need such as removal of riparian vegetation and dredging organic matter from ponds to prevent organic matter accumulation and hypoxia from occurring.

The second strategy would lower the floodplain elevation by excavation, thereby increasing inundation frequency to impede vegetation growth, reduce organic matter inputs, and increase flushing flows. This strategy mainly emphasizing on habitat creation in some respects by way of excavating the floodplain and restoring floodplain connectivity and flooding processes, which in turn result more sustained reduction of the inputs of organic matter and increased flushing flows.

Finally, the third strategy of restoring the sediment supply (the primary impaired process) makes the channels viable over long term and ultimately restores floodplain connectivity by facilitating more natural floodplain inundation frequency. In many cases, such combined and integrated approaches are used in restoration, especially in cases where short-term manipulations (habitat improvement) can be combined with long-term process restoration (full or partial process restoration).

Nevertheless, such actions can be designed in the context of the process-based principles to improve restoration effectiveness and longevity. While the first principle may not apply (it may not be possible to address the root cause of degradation), the remaining principles guide restoration or habitat creation actions to be (**1**) consistent with local physical and biological potential (which is altered by human constraints), (**2**) at an appropriate and correct scale for the location and problem, and (**3**) reasonably limited in expectations for the restoration outcome (Beechie et al. 2010).

8.28.3 Ecological Concept of Ecosystem Resilience: Relevant Restoration Programs

The ecological concept of resilience refers to the ability of a system to "absorb disturbance and also to retain almost the same structure, function, identity, and feedbacks" (Holling 1973). In the case of river restoration, restoring floodplain connectivity, restoring variable flow regimes, or restoring migration pathways between diverse habitats will increase the ability of systems to reorganize both physically and biologically in response to climate change (Waples et al. 2009).

Because there are significant uncertainties in predicting future habitat conditions using climate and hydrologic models, a precautionary approach to identifying restoration actions for long-term benefits is to ensure that river ecosystems are physically and biologically able to adjust to a changing environment. Building ecosystem resilience has been considered critical to ecosystem restoration for the past decade, even without considering climate change (Bottom et al. 2011).

In a review of restoration actions that either ameliorate climate change effects or increase resilience, Beechie et al. (2012) identified a suite of actions that are most likely to maintain their effectiveness in a future climate. Most importantly, actions that increase floodplain connectivity, maintain access to diverse habitats, and restore exchange between surface water and groundwater are most likely to improve riverine ecosystem resilience in a changing climate (Waples et al. 2009). By contrast, actions that restore watershed processes are moderately likely to ameliorate climate change effects, whereas most instream restoration actions are not likely to sustain their effectiveness in a future climate data.

8.29 River Floodplain Restoration

There is growing understanding of the significance of the strong hydrological, geochemical, and biological links between channel and surrounding land which affect aquatic ecosystems, and with this, the importance of the floodplain river corridor within river restoration is being increasingly recognized (Brookes 1995a; Brookes and Shields 1996; Holmes 1998). Rehabilitation and restoration of floodplains can have varying positive effects on river channel attributes and functions (Brookes et al. 1996). The separation of floodplains from the hydrological and geomorphological systems of the channel is now seen to be a potentially counterproductive aspect of conventional approaches to river control mainly because of cost-effectiveness.

Restoration of floodplain environments may result from management intervention in any of the three contexts: the catchment, the river corridor, and the channel. In the catchment, it may be promoted by non-structural interventions (affecting land use), which allow natural recovery of floodplain ecosystems from some anthropogenic perturbation (Perrow and Wightman 1993). Full restoration of floodplain ecosystems must involve restoration of the flood pulse (Bayley 1991; Brookes et al. 1996). Floodplain restoration may therefore be defined as re-establishment of the abiotic and biotic elements of ecosystems within the river environment, including floodplain and riparian land connected to the river, such that appropriate processes of inundation, erosion, and deposition are-established that can themselves recreate riparian and floodplain ecosystems and the wildlife and landscape values that are associated with them. It is clear that river restoration must take account of the links between rivers and their floodplain and riparian zones. However, floodplain restoration is more complex and problematic than channel restoration. The increasingly sophisticated techniques and growing experience of channel restoration are not sufficient basis for floodplain restoration.

Four problems place particular constraints on floodplain restoration: (**1**) scientific complexity, (**2**) technical capacity, (**3**) formal, and (**4**) informal institutions controlling floodplain management.

8.29.1 Scientific Complexity and Floodplain Restoration

Many of the problems encountered during floodplain restoration are derived from the inherent complexity of floodplain ecosystems and to a limited extent because of the dearth of scientific understanding of the existing eco-dynamism of this unique eco-region in space and time. This complexity derives from four sources.

First, floodplains or "riverine riparian ecosystems" (National Research Council 1992) zones are spatially diverse, both laterally and longitudinally. There is great lateral variability in elevation, sediments, water regime, and vegetation. The structure and function of riparian or floodplain environments also vary longitudinally. The National Research Council (**NRC** 1992) has opined that higher aquatic production is centered on the channel in the upper reaches and in the floodplain further downstream. Riparian zone upstream receives inputs of water, nutrients, and sediment from hill slopes and filter them before they reach the river; floodplains are zones of interchange, receiving inputs from the channel, buffering inputs to the channel, and generating endogenous processes and products.

Second, there are complex systemic links both laterally and longitudinally within a single river catchment system. There are complex lateral links between floodplains and river channel environments that involve physical processes and pathways (both hydrological and chemical) and biological processes (plant litter and fish). They are reciprocal, in that under some circumstances floodplain ecosystem processes will have implications for channel ecosystems, whereas in others, the reverse will hold.

Third, these lateral links interact with longitudinal interactions between upstream and downstream reaches. Although river restoration managers may have to think in terms of discrete "**sites**" or reaches, rivers connect these pieces together in complex ways, so that upstream change (whether natural or anthropogenic) in channel, floodplain, or catchment can have significance for the response of downstream floodplains.

Fourth, floodplain ecosystems are complex temporally. There are time lags between changes in different abiotic systems and in between abiotic and biotic systems. These interactions have complex knock on effects on floodplain systems, such that the evolution of floodplain ecosystems is highly contingent in space and time, and prediction of likely patterns of change is problematic. Furthermore, some characteristic floodplain species have long life spans (notably floodplain trees).

Therefore, where the signature of past events lingers for several generations, this can imply a period of centuries, probably predating direct flow measurements and much documentary evidence on the river. Similarly, present management actions may have effects that resonate well beyond the conventional time horizons used in economic appraisals by project planners (often 30 years).

8.30 Restoration Strategy: Fish as Model for Spatial and Temporal Heterogeneity

Habitat heterogeneity across a range of scales is a fundamental characteristic of aquatic systems (Frissel et al. 1986; Townsend and Hildrew 1994; Palmer and Poff 1997; Crook et al. 2001; Ward et al. 2001). Most of the fish are found to inhabit a wide range of habitats within a river system, but a good number of species show distinct habitat preferences. Different guilds of fishes utilize multiple types of spawning substrata, and the chance of higher survivability of fish larvae and juveniles depends upon the availability of suitable nursery grounds (Mann 1996; Copp 1997; Cowx and Welcomme 1998).

Additionally, habitat complexity determines the structure and diversity of fish community and triggers resilience to disturbance (Gorman and Karr 1978; Schiemer et al. 1991; Pearsons et al. 1992). Hence, the distortion of structural complexity and destruction of spawning and nursery habitats through the alteration of geo-hydrology of river and sometimes river channelization cause drastic changes in assemblages of fish fauna (Mann 1988; Swales 1988). These impacts are aggravated because of the rapid deterioration of the water quality associated with changes in the land uses, especially the intensified agriculture (Mason 1996). Numerous studies have highlighted the massive decline in the diversity and density of fish fauna because of the channelization in lowland rivers in Britain (Swales 1982, 1988; Spillet et al. 1985; Cowx et al. 1986; Punchard et al. 2000).

Similarly, studies from warm water rivers in North America (Chapman and Knudsen 1980; Edwards et al. 1984, 1986) and rivers in Northern Europe (Jungwirth et al. 1993; Muotka and Laasonen 2002) have justified the positive roles of habitat heterogeneity in promoting higher diversity of aquatic fauna and also highlighted the negative impact of channelization on both benthic and nektonic fauna. In several rivers, sediment transport, erosion, and deposition following certain pathways and obeying definite patterns unique for those river systems enable the affected rivers to come back to its earlier form and recover natural geo-morphological features such as riffles and pools following channel modification (Brookes 1985, 1992; Hey 1992).

Out of several techniques involved in restoring natural rivers, most used techniques include the narrowing and re-meandering of channelized reaches, reprofiling banks very steep banks, and creating specific features such as riffles and backwaters (Cowx and Welcomme 1998; RRC 1999). This suggests that fish may respond positively to an increase in flow velocity in manipulated reaches, but the absence of any other relationships may indicate that physical/biological relationships are not simple and may be influenced by other factors. There was little evidence from this study that adding artificial riffles or flow deflectors substantially improved the conservation value of the fish assemblage, in terms of abundance, species richness, diversity, and equitability. The rehabilitation efforts have been seen to be successful by enhancing the habitat heterogeneities and by manipulating the riverine flows, variability of depth, and velocity of currents of water in different catchments and reaches of rivers.

However, the fish fauna do not vary significantly between different manipulated zones indicating that alteration of physical condition over a significant area can only make significant effects on fish fauna. Besides, as vegetational assemblages with specific composition of species contribute for developing habitat complexity in lowland rivers, in comparison with high gradient rivers where channel morphology displays more variability. Besides, the ecological functioning of lowland rivers is determined by occurrences of floodplain habitats which play very crucial roles in shaping the morphology and also regulating the biodiversity (Gore and Shields 1995) vegetated margins. The backwaters connected to the main river and supported by unique assemblages of vegetation provide suitable habitats for not only the adult fish but also their juveniles in the lowland rivers (Garner 1996, 1997; Copp 1997; Lusk et al. 2001).

Similarly, restoring floodplain connectivity has appeared to be beneficial to the riverine biota, as well as riparian plants and animals (Audsen et al. 2001; Robertson et al. 2001). In such context, it can opined that the creation of off-channel, marginal, and floodplain habitats may become better strategy for rehabilitating lowland rivers and thereby providing fish and other riverine biota to settle, grow, and propagate.

8.30.1 Does the Fish Fauna Have the Potential for Increased Density or Richness?

Aquatic communities being naturally resilient to environmental disturbance (Giller and Myers 1996) are able to recover following the rehabilitation of degraded habitats. However, the potential of different species of fish either in an isolated manner or becoming an assemblages of fish to respond to the improving habitats after rehabilitation of the habitats following two options: firstly, on whether water quality is sufficient to support a diverse fish assemblage and secondly, whether existing populations can disperse to, and exploit, the improved habitat. The failure of any fish to display positive responds to such habitat rehabilitation is reflected by one or both of these factors.

Fish habitats with higher nutrient enrichment coupled with extensive growths of filamentous algae (*Cladophora* spp.) show impoverished fish assemblages and low **biological monitoring working party (BMWP**) scores. These observations suggest that water quality might be a limiting factor for fishes in these rivers.

Not only the water quality as the prime limiting factor, other factors are supposed to influence the fish response. Research studies have been conducted to assess the positive impact of habitat rehabilitation in influencing biological recovery based on the diversity and distribution of invertebrates (Fuchs and Statzner 1990; Wiberg-Larsen 1999).

8.31 Impact of Interactions Between Flooding and Upland Disturbance

Driving force to shape biological environment within river floodplains being one of the complex and productive ecosystems, river floodplains provide essential ecological and economic services to the human society by ensuring drought protection, fisheries development, and agricultural production. Besides, they also maintain the balance of the nature by providing favorable habitats and food sources for both aquatic and terrestrial organisms. However, the appropriate functioning and provision of floodplain ecosystem services to humans and nature depend on the degree and frequency of connectivity with the upstream river system. Both of these factors have drastically changed in rivers around the world, primarily as a result of water infrastructure developed to regulate water for hydropower, water supply, and irrigation.

Although water infrastructure development has presumably already resulted in drastic alterations to the hydrology and biota of vast areas of floodplains around the world, challenges, it has been accelerating the pace of economic development and thereby impact conservation strategies for those large but unregulated rivers (Grill et al. 2015). The prevailing climatic changes also impose its negative impacts on floodplains by reducing biological productivity, alterations of hydrological events, enhancement of temperatures, and salt intrusion (Hamilton 2010; Junk et al. 2013). Several restoration efforts have been made all over the world with the focus on conservation of biological resources, climate change adaptation, proper prediction of long-term ecological patterns, and the mode of linkages of the hydrology with the ecosystem functioning as a part for ensuring the sustainable management of large rivers and their floodplain ecosystems (Sullivan et al. 2014), Mississippi River (Mitsch and Day 2006), and Colorado River (Glenn et al. 2013).

8.31.1 Development of Conceptual Models Based on Case Studies

Several conceptual models have been proposed to depict the mode of influence of inundation patterns, hydrological alterations, and consequent controlling plant species diversity along the ecological gradients in large river floodplains through annual to decadal time scales. Case studies of four large floodplains on three continents viz. the Mekong, the Amazon, Pantanal, and Okavango in the light of species richness patterns were undertaken in the field and the research outcomes were used to relate to the conceptual model so that the ecodynamics of those major ecoregions could be assessed and compared.

8.31.1.1 Current Status and Future Perspective of Large River Floodplains

Nearly half of the world's large rivers that once had extensive floodplains are now regulated for hydropower, irrigation, or flood control (Nilsson et al. 2005; Lehner et al. 2011). Looking first at the distribution of floodplain wetlands and forests around the world as mapped by Lehner and Döll 2004), it is clear that most of the seasonally inundated areas are part of major river basins within the tropics like the large rivers, Orinoco, Paraguay, and the Amazon in South America; Congo and Zambezi in Africa; and Indus, Ganges, Mekong, and Yangtze in Asia. However, all these rivers have drastic differences in the degree of their hydro-geological alterations caused by water infrastructure development as highlighted by the map of river dam regulation by Lehner et al. (2011). For instance, there are very high levels of regulation in the Mississippi and Indus- Ganges basins, where intensive irrigation agriculture is dominant. The Mekong and Yangtze rivers in Southeast Asia, with large hydropower dams in their headwaters, have comparatively mild levels of regulation. The mainstream of the Amazon and Congo – the rivers with the largest discharge have had little regulation in past decades, despite recent efforts and future plans to construct large dams in both basins (Winemiller et al. 2016). These differences in degree of river alteration are also a direct reflection of the ecological and biodiversity status of their floodplains, which is certainly most impoverished in heavily altered rivers like the Mississippi and best preserved in the least regulated Amazon and Congo.

8.31.1.2 Hydrological Controls in Floodplain Species: Convergence of Ecological Concepts

In order to conceptualize the link between hydrological controls and diversity patterns in large river floodplains, it is important to provide the theoretical framework underlying this relationship. A general model of spatial biocomplexity across river networks has been proposed as the riverine ecosystem synthesis by Thorp et al. 2006, and the prime objective of all conceptual models are to synthesize and harmonize knowledge from the prevailing concepts of critical importance to the understanding and management of large river floodplains.

In particular, there are two widely known concepts exist in the realm of freshwater ecology in this regard: (**1**) **intermediate disturbance hypothesis (IDH)** (Connell 1978) and (**2**) **flood pulse concept (FPC)** (Junk et al. 1989).

8.31.1.2.1 Intermediate Disturbance Hypothesis (IDH)

The intermediate disturbance hypothesis (**IDH**) points out that maximum levels of biological diversity occur at intermediate levels of disturbance in respect of time and space. However, intense disturbance creates a condition which promotes the establishment and propagation of some pioneering species, whereas low disturbance facilitates the eventual dominance of a selected number of climax species. Therefore, intermediate stages of disturbance represent a transitional phase having the required niche to assure fruitful coexistence of pioneering, intermediate, and climax species. This hypothesis first proposed by Connell (1978) based on his research on rainforest and coral ecosystems received wide acceptance and promoted other ecologists to apply **IDH** to some other major ecosystems with satisfactory results (Petraitis et al. 1989; Mackey and Currie 2001; Molino and Sabatier 2001; Tanentzap et al. 2013; Jardine et al. 2015).

IDH has been successfully applied to floodplain ecosystem which represents an interphase zones between terrestrial and aquatic ecosystems (Naiman and Décamps 1997), accommodating species which inhabit in both types of ecosystems. Distinct unimodal modes of population fluctuation of some species as predicted by the **IDH** have been observed as a function of flooding frequency (Pollock et al. 1998), and species diversity patterns in the aquatic systems are thought to be due to the result of differences in species' niches rather than demographic stochasticity (Tanentzap et al. 2013). Zelnik and Carni (2008) found the linear increase of species richness as a terrain elevation along a wetland moisture gradient surrounded by a landscape with low land-use intensity which tends to contradict the **IDH** predictions.

8.31.1.2.2 A Conceptual Model of Species Diversity for River Floodplains

Based on these two ecological concepts dealing with spatial distribution of organisms inhabiting in river floodplains, a conceptual model has been developed in which species diversity varies in floodplain landscapes as a function of flooding patterns and the land-use conditions that dominate the adjoining and surrounding upland areas. Large river floodplains mostly occurring along low terrain elevation gradients tend to develop strong flooding gradient because of the seasonality in the flood pulse and returns to its conducive state with diminishing of flooding intensity and frequency. Ecological status for the growth and propagation of inhabitant biota may become more favorable because of some other upland disturbances such as agriculture, drought, and fire which are supposed to operate in the opposite direction of flooding, representing an upland disturbance gradient.

Unregulated flooding has appeared to be a regular natural phenomenon in most of the large river floodplains especially in tropical countries where the flooding gradient being a disturbance mechanism determines the occurrence of those species that cannot tolerate water logging. Floodplains support the lives of a unique set of species exclusively suitable for these habitats having different degrees of tolerance to flooding because of the impact of such flooding gradient. In case of marginal seasonal flooding due to upstream factors (water resources development), species diversity is more likely to be determined by external (upland) disturbances, both anthropogenic (agriculture, deforestation, etc.) and natural (drought and fires) (Arias et al. 2018).

8.31.1.2.3 Ecology of River Floodplain: The Impact of Disturbances – Case Studies

Species diversity of four large floodplain systems across the tropics in South America, Africa, and Asia experiencing distinct seasonal flood pulses with low levels of flow regulation has been studied and compared with the surrounding uplands, characterized by different environmental conditions and disturbance types (Arias et al. 2018). This study has partially explained variations in plant species diversity gradients among these floodplains, and the last species was found to be an aggressive invasive ones that has been observed primarily on sites cleared in recent years (Arias et al. 2013), and this observation led to develop the hypothesis that increased disturbance tends to enhance the spreading of the invasive species.

Species diversity was found to reach a peak in an area which experience inundation for a period of **3–5** months per year, mainly because of two factors. **First**, a diverse set of natural and agricultural habitats coexist in this zone. **Second**, Less duration and depth of inundation provide more scopes for cropping, especially with traditional varieties of floating rice which have been in use by the local peoples for a long time in the past, but their usages have been declining, since a few decades back because of some disturbances (natural fire, floods, civil wars, etc.), and then transition to conventional rice varieties unable to withstand deep flooding for long periods of time (Nesbitt 1997; Sarkkula et al. 2003).

In addition to habitat diversity, the increase of species diversity in the nonagricultural area among all floodplain habitats of this ecosystem with decreasing flooding intensity is expected to enhance favorable conditions for terrestrial plant growth, mostly dominated by grasses, while the proportion of sedges increases downslope toward the longer hydroperiod zones (Smith 1996; Murray-Hudson et al. 2011). The floodplains enjoying perennial flooding usually harbor hydrophytes exhibiting lower diversity than the areas which experience a dry period at the low point of each pulse. Research information from the seasonal floodplains (Murray-Hudson et al. 2015) indicates that peaks in species richness and diversity occur at medium (**6** month) and high (**10** month) mean annual flood duration, and the species abundances reached to a lowest level only during dry and wet ends of the seasons. Murray-Hudson et al. (2015) based on their research concluded that depth of flooding coupled with higher flood frequencies comes into play as a driver of composition. The aforesaid case studies have enabled to derive some concluding remarks such as:

1. Spatial distribution of species diversity along inundation gradients in large river floodplains can be explained by the interaction between two critical environmental drivers: flooding and upland disturbances.
2. These two drivers interact in unregulated floodplains, in order to determine the frequency and magnitude of flooding and their prospective influence in shaping the extent and type of land use and cover that takes place in a floodplain.
3. Peak species diversity is resulted at intermediate stages along the disturbance gradient in the floodplain regions, whereas the upland conditions face strong external disturbances.
4. Interlinkages among elements from two well-established ecological concepts, the **intermediate disturbance hypothesis** (Connell 1978) and the **flood pulse concept** (Junk et al. 1989), have appeared to possess excellent synergy when explaining the origin, development, and patterns of species diversity in floodplains.

8.32 Decadal Case Study of Wasteland Restoration from Riverine Basin of Kansai River, South West Bengal, India

Deteriorating socio-ecological state is a common incidence where shrinkage of forest coverage, the loss of species, and destruction of habitats for biodiversity occur. Both wetlands and forests contribute separately toward sustainable development; the baseline knowledge regarding the interlinkages and interdependence between the two have appeared to prerequisite for undertaking effective restoration efforts for the degraded ecosystems in their entirety in respect of guarding their ecological characters and related **ecosystem services (ES)** that are vital to human activity.

A recent study was undertaken to explore the role of eco-restoration efforts within forest–wetland ecosystem, not only to develop conserving strategies for biodiversity but also for maintaining the sustained flow of **ES**, in the multi-decadal recovery of a degraded landscape, named as Gurguripal forest, and located at Midnapore (West) district of the state West Bengal, India (Figs. 8.7, 8.8 and 8.9). This entire long-term study was conducted with the help of geospatial technology and generating ground truth information through field surveys of biodiversity and socio-ecological

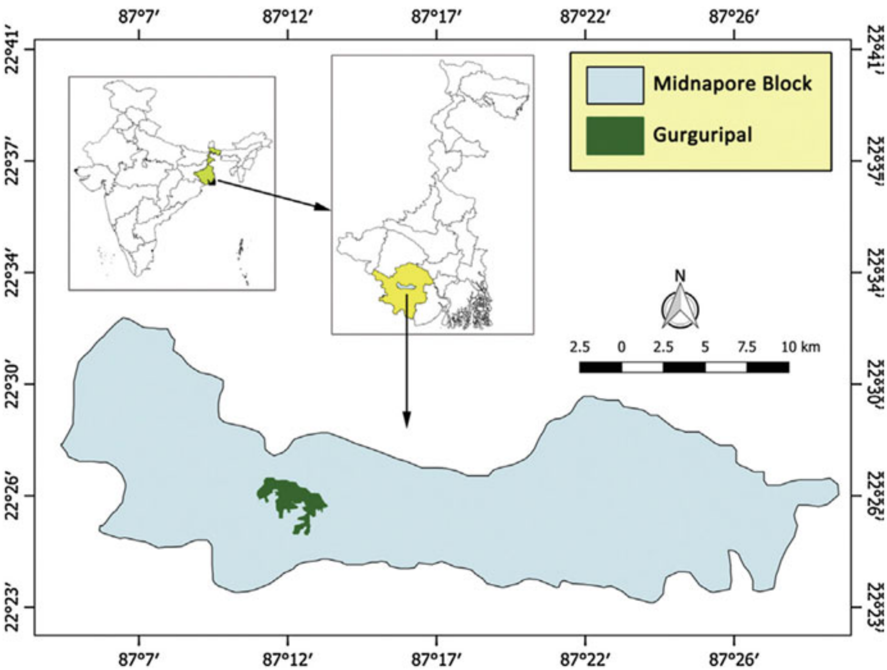

Fig. 8.7 Map showing the location of eco-restored forest belt (Gurguripal) at Midnapore (West), West Bengal, India

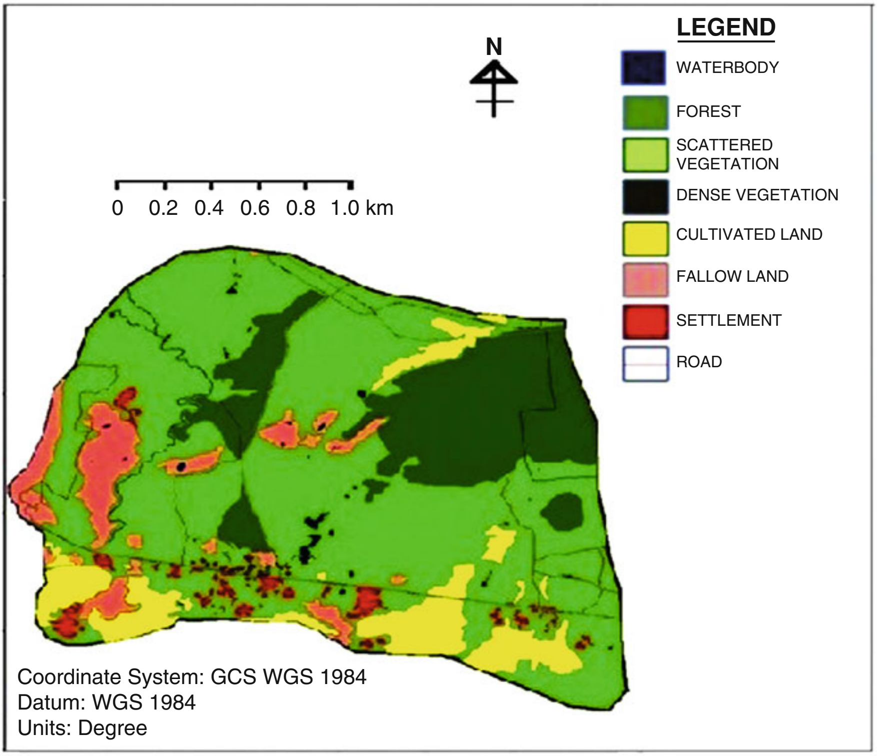

Fig. 8.8 Land-use pattern at a specific study site for eco-restoration program (Gurguripal) at Midnapore (West), West Bengal, India. (After Halder and Chakraborty 2018)

components (Halder and Chakraborty 2019). The role of forests in regulating the hydrological cycle by controlling sedimental flow, reducing erosion rates, and influencing both horizontal and vertical movements of water in a riverine beds and associated watersheds and also preservation of wetlands has been elaborated by Blumenfeld et al. (2009). Actual understanding on the interlinkages and inter-dependences between wetlands and forests has appeared to be very important as per as the eco-management of ecosystems in their entirety is concerned in order to protect their ecological characters along with discharging ecosystem services (McElhinny 2002).

Declining ecosystem vitality, because of increasing water stress coupled with the shrinkage of forest cover, acts as main actors causing socio-ecological degradation (Davies et al. 2016). Therefore, eco-restoration being the process leading to the recovery of a degraded ecosystem (Bradshaw 1987; SER 2004) helps arresting the ongoing eco-deterioration and also rejuvenating such poor health of environmental conditions alongside providing resilience to an area of concern. Proper assessment of the effects of successful execution of different restoration approaches on recovery of ecosystem services has appeared to be very difficult despite wide recognition of the

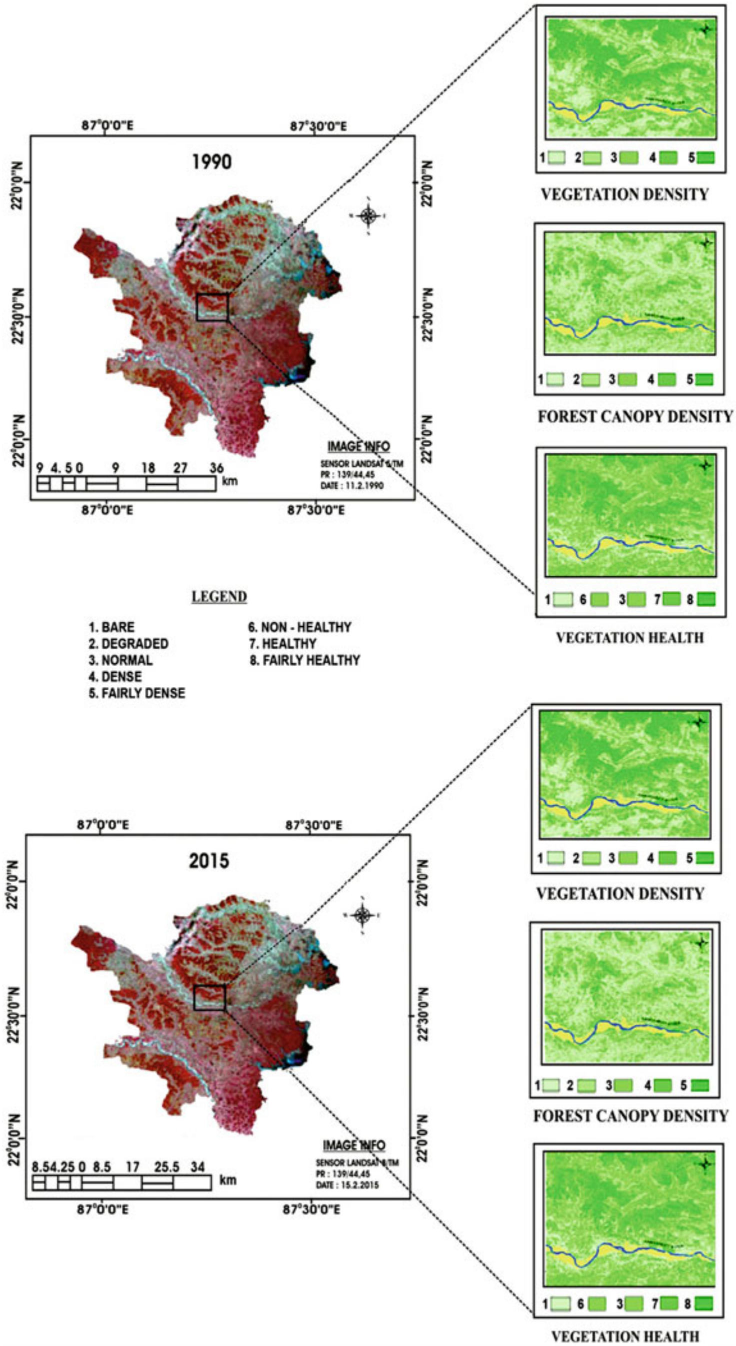

Fig. 8.9 Satellite imageries at different time scales (1990, 2015) at a specific restoration site (Gurguripal) at Midnapore (West), West Bengal, India. (After Halder and Chakraborty 2018)

links and interplays among biodiversity, functional traits, and ecosystem services (de Bello et al. 2010). Over the last decade, West Bengal in India has pioneered in involving the local peoples, mostly belong to marginalized section of the society of erstwhile Midnapore and Purulia districts forming forest protection community in order to protect local forests so that natural regeneration be encouraged (Mishra and Roy 2002; Singh 2008).

This case study has unearthed valuable information of the outcomes of repeated initiatives of conservation by government in collaboration with people's participation on previously all most undulating lateritic terrains with sparse forest coverage experiencing intense erosion pressures during the past decades. In such context, the uniqueness of such case study on the impact of eco-restoration on eco-degraded forest wasteland in the lateritic tracts of Midnapore (West) district of West Bengal, India, revolves around the decadal ecological changes coupled with changes on socioeconomic profiles of the region has been established.

8.32.1 Physiography of the Study Area: An Eco-restored Wasteland, Gurguripal, West Bengal, India

Gurguripal forest, under the forest division of Midnapore (West) district West Bengal, India, very close to the riverine flows of the river, Kansai at the vicinity of Midnapore City of the Midnapore (West) district of the state of West Bengal, India. The entire area is characterized by mostly the lateritic soils having dry deciduous forest mostly with dominated by sal trees (*Shorea robusta*). Shorea as the dominant species experience high temperature (maximum **45 °C** during summer and minimum **8 °C** during winter) and moderate rainfall (average **1600** mm) during monsoons.

8.32.2 Forest–Wetland Complementation and Ecological Development

8.32.2.1 Complementary Roles of Forest and Wetland in Eco-Restoration

The study of forest ecosystem generally includes the species composition of different categories of plants, their growth and distribution, trophic interactions, and nutrient cycling for ensuring not only the ecological stability but also promoting different forms forest-dependent biodiversity components. However, a recent study has unearthed some useful information on the roles of forest functioning toward management and conservation of soil and water taking into consideration of recent ecological past of the forest management which in turn helped sustaining the adjoining ecosystem such as wetland ecosystem by developing the forest–wetland complex.

The complementary roles played by both forests and wetlands as complementary amalgamation of two distinct ecosystems e.g. forest and water promote post-rejuvenation, of biodiversity, maintain the desired morphometry of the wetlands for higher productivity, recharging of groundwater which in turn help water retention within the wetland, and enhancement of soil moisture and other physicochemical attributes necessary for biodiversity development and human dependence (Halder and Chakraborty 2018).

8.32.2.2 Ecological History of Gurguripal Forest: Prior and After Eco-Restoration – A Case Study

The Gurguripal forest belt located in the dry and laterite ecozone had become unproductive due to large-scale deforestation for a couple of decades since the **1950s** resulting in the formation of several patches of wastelands within forest, soil erosion progressed at an ever-increasing pace, and a number of water bodies became seasonal because of steady decrease of the groundwater levels during that period (Figs. 8.7, 8.8, and 8.9). Owing to the dearth of forest-based resources, most of the villagers switched over their livelihood by way of illegal boulder mining and tree falling. Earlier, around six decades back, the villagers, mostly female members of the family, had to collect buckets of water from the nearby Kansai River mainly for drinking after making about **5–6 km** walks even in the hot summer days. Initially, considering the gravity of the poor ecological condition in that area, the Forest Division, Government of West Bengal, India, initiated aforestation program during the **1960**s as part of eco-restoration efforts, and ultimately, the entire area was successfully covered up with the green forests during the **1980**s.

Simultaneously, the officials of the Forest Department of that area taking the help of local peoples took up the job of convincing the villagers in and around the forest tracts about the hazards of soil erosion and importance of afforestation and soil moisture conservation as a facilitating program for boosting the socioeconomic upliftment of the people of the region. Alongside the plantations, a good number of structural constructions, **viz**., earthen dams, check dams, gully plugs, etc. were done which helped groundwater recharging effectively as well as arrest soil erosion. Lateritic gullies which were formed during the conversion of forests into wastelands during several decades back in conjunction of the rejuvenated green coverage reduce horizontal seepage and increase vertical percolation of water so that groundwater recharging could be elevated which have been reflected by the increased surface water table.

The excellent groundwater recharging coupled with retention of moisture of the soils, single-crop agriculture system has been converted into multiple crop cultivation, and good availability of drinking water facilitated the inhabitants as a relief. Besides, another remarkable ecological changes of such successful eco-restoration project are reflected by the transformation of the seasonal wetlands into perennial water bodies in and around the forest belts promoting the growth and developments of both terrestrial forest-based and aquatic biodiversity including several wildlifes (Halder and Chakraborty 2018).

Far-reaching effects on human well-being are rendered by the continuous and steady interactions within healthier forest-wetland ecosystem which provides both tangible and non-tangible goods and essential lifesaving ecological services especially as the sources in the form of oxygen, drinking water, and different other commodities for the livelihoods of local people. This case study has highlighted the positive contribution of the conservation strategies based on systematic, strategic, and integrative planning in ensuring resilience of the forest ecosystem, by maintaining the intricate relationship among various structural components, actors, and ecological processes in a habitat; activating the participatory roles of local people's in accelerating natural recovery process; understanding the significance and proper execution of the geospatial techniques in capturing the past; and nevertheless the role of public perception in evaluating ecosystem services.

8.33 Community-Based Restoration

Restoration emerged from the broader ecological movement as a practical way to address the degradation of rivers and streams and can be seen as part of a phase of resource reconstruction arising from changing societal priorities. Such wider objectives of river restoration instead of aiming only to ensure simple ecological improvement are to have community building exercises by involving local or regional inhabitants having knowledge of ecological past and present. In order to derive maximum ecological benefits from the restoration efforts, increasing focus on ecological principles is now made alongside fulfilling the legislative requirements by undertaking appropriate designing for monitoring of the changing ecological conditions and also attaching more emphasis on community-based activity (Chakraborty et al. 2009; Chakraborty, 2013). This approach has necessitated to blend participatory approaches and an ecosystem goods and services approach by integrating restoration motives and drivers with social and scientific goals. This increasing importance of community groups in river restoration represents both an opportunity and a challenge. However, the success of this approach depends by reconciling the conflicts between stakeholders acknowledging the complex and dynamic nature–society relationships that interact to support **well-being** or **cultural value**.

Two developments, however, provide grounds for optimism that river restoration can address the undermentioned points.

First, the potential for community groups to be involved in the collection of data and monitoring of projects, by developing more productive relationship between scientists and nonscientists but also a much clearer idea of the barriers and constraints to effective restoration.

Second, the increasing ability to link, combine, and analyze large datasets and the huge amount of data now available through remote-sensing techniques provide new avenues for exploring relationships between ecology and geomorphology. The history of river management focuses multifarious ecological changes involving a highly dynamic relationship between nature and society mostly resulting an eco-degradation of rivers which are needed for effective eco-restoration. Different trial and error processes are supposed to have been carried out in different parts of the world having varied forms of agroclimatic conditions for standardizing and implementing the river restoration programs and thereby generate new avenues for the evolution of more acceptable methods for the river restoration. The challenges for so many environmental managers and stakeholders are to act as facilitators for ensuring this evolution leading to successful river restoration which play an integral role in the creation of healthy, functioning rivers while meeting societal demands for such things as flood protection, recreation, and aesthetic value.

References

Aber, J.D. 1987. Restored forests and the identification of critical factors in species-site interactions. In *Restoration ecology. A synthetic approach to ecological research*, ed. W.R. Jordan, Gilpin, and J.D. Aber, 241–250. Cambridge: Cambridge University Press.

Allan, J.D. 2004. Landscapes and riverscapes: The influence of land use on stream ecosystems. *Annual Review of Ecology, Evolution, and Systematics* 35: 257–284.

Allen, T.F.H., and T.W. Hoekstra. 1992. *Toward a unified ecology*. New York: Columbia University Press.

Allen, T.F., and T.B. Starr. 1982. *Hierarchy: Perspective for ecological complexity*. Chicago: The University Chicago Press, 310 pp.

Allen, E., W.W. Covington, and D.A. Falk. 1997. Developing the conceptual basis for restoration ecology. *Restoration Ecology* 5 (4): 275–276.

Angelsen, A., M. Brockhaus, M. Kanninen, E. Sills, W.D. Sunderlin, and S. Wertz-Kanounnikoff, eds. 2009. *Realising REDD +: National Strategy and policy options*. Boor: CIFOR.

Arias, M.E., T.A. Cochrane, T. Piman, M. Kummu, B.S. Caruso, and T.J. Killeen. 2012. Quantifying changes in flooding and habitats in the Tonle Sap Lake (Cambodia) caused by water infrastructure development and climate change in the Mekong Basin. *Journal of Environmental Management* 112: 53–66.

Arias, M.E., T.A. Cochrane, D. Norton, T.J. Killeen, and P. Khon. 2013. The flood pulse as the underlying driver of vegetation in the largest wetland and fishery of the Mekong Basin. *Ambio* 42: 864–876.

Arias, M.E., T.A. Cochrane, M. Kummub, H. Lauric, G. Holtgrieve, J. Koponenc, and T. Piman. 2014. Impacts of hydropower and climate change on drivers of ecological productivity of Southeast Asia's most important wetland. *Ecological Modelling* 272: 252–263.

Arzel, C., and J. Elmberg. 2015. Time use and foraging behavior in pre-breeding dabbling ducks Anas spp. in sub-arctic Norway. *Journal of Ornithology* 156: 499–513. 134 Hydrobiologia (2017) 804:119–137.

Austin, J.E., T.K. Buhl, G.R. Guntenspergen, W. Norling, and H.T. Sklebar. 2001. Duck populations as indicators of landscape condition in the Prairie Pothole Region. *Environmental Management and Assessment* 69: 29–47.

Baillie, J., C. Hilton-Taylor, and S.N. Stuart, eds. 2004. *2004 IUCN red list of threatened species: A global species assessment*. Cambridge: IUCN.

Bajer, P.G., G. Sullivan, and P.W. Sorensen. 2009. Effects of a rapidly increasing population of common carp on vegetative cover and waterfowl in a recently restored Midwestern shallow lake. *Hydrobiologia* 632: 235–245.

Baker, A.J.M., S.P. McGrath, R.D. Reeves, and J.A.C. Smith. 2000. Metal hyperaccumulator plants: A review of the ecology and physiology of a biological resource for phytoremediation of metal-polluted soils. In *Phytoremediation of contaminated soil and water*, 85–107. Boca Raton: CRC Press L.L.C.

Barber, W.E., and J.N. Taylor. 1990. The importance of goals, objectives, and values in the fisheries management process and organization: A review. *North American Journal of Fisheries Management* 10: 365–373.

Barinaga, M. 1996. Life-death balance within the cell. *Science* 274 (5288): 724–724.

Bayless, J., and W.B. Smith. 1967. *The effects of channelization upon the fish population of lotic waters in eastern North Carolina*. Proceedings, annual Conference S.E. Association Game and Fish Community, no.18, pp. 230–238.

Bayley, P.B. 1991. The flood pulse advantage and the restoration of river-floodplain systems. *Regulated Rivers: Research & Management* 6: 75–86.

———. 1995. Understanding large river-flood-plain ecosystems. *Bioscience* 45: 153–158.

Beechie, T., and S. Bolton. 1999. An approach to restoring salmonid habitat-forming processes in Pacific Northwest watersheds. *Fisheries* 24: 6–15.

Beechie, T.J., M. Liermann, M.M. Pollock, S. Baker, and J. Davies. 2006. Channel pattern and river-floodplain dynamics in forested mountain river systems. *Geomorphology* 78 (1–2): 124–141.

Beechie, T.J., G. Pess, P. Roni, and G. Giannico. 2008a. Setting river restoration priorities: A review of approaches and a general protocol for identifying and prioritizing actions. *North American Journal of Fisheries Management* 28: 891–905.

Beechie, T.J., H. Moir, and G. Pess. 2008b. Hierarchical physical controls on salmonid spawning location and timing. In *Salmonid spawning habitat in rivers: Physical controls, biological responses, and approaches to remediation*, American Fisheries Society, Symposium 65, ed. D. Sear and P. De Vries, 83–102. Bethesda.

Beechie, T.J., G.R. Pess, M.M. Pollock, M.H. Ruckelshaus, and P. Roni. 2009. Chapter 33: Restoring rivers in the 21st century: Science challenges in a management context. In *The future of fisheries science in North America*, ed. R.J. Beamish and B.J. Rothschild, 695–716. Heidelberg: Springer.

Beechie, T.J., D. Sear, J. Olden, G.R. Pess, J. Buffington, H. Moir, P. Roni, and M.M. Pollock. 2010. Process based principles for restoring river ecosystems. *Bioscience* 60: 209–222.

Bellrose, F.C., S.P. Havera, F.L. Paveglio Jr., and D.W. Steffeck. 1983. The fate of lakes in the Illinois River Valley. *Illinois Natural History Survey Biological Notes* 119.

Benda, L., L.R. Poff, D. Miller, T. Dunne, G. Reeves, M. Pollock, and G. Pess. 2004. Network dynamics hypothesis: Spatial and temporal organization of physical heterogeneity in rivers. *Bioscience* 54: 413–427.

Bentham, H., J.A. Harris, P. Birch, and K.C. Short. 1992. Habitat classification and soil restoration assessment using analysis of soil microbiological and physiochemical characteristics. *Journal of Applied Ecology* 29: 711–718.

Berkes, F., C. Folke, and M. Gadgil. 1994. Traditional ecological knowledge, biodiversity, resilience and sustainability. In *Biodiversity conservation, ecology, economy and environment*, ed. C.A. Perrings, K.G. Maler, C. Folke, C.S. Holling, and B.O. Jansson, vol. 4, 269–287. Springer.

Bernhardt, E.S., and M.A. Palmer. 2011. River restoration: The fuzzy logic of repairing reaches to reverse catchment scale degradation. *Ecological Applications* 21: 1926–1931.

Bernhardt, E.S., M.A. Palmer, J.D. Allan, G. Alexander, K. Barnas, S. Brooks, et al. 2005. Ecology – Synthesizing US river restoration efforts. *Science* 308: 636–637.

Bernhardt, E.S., E.B. Sudduth, M.A. Palmer, J.D. Allan, J.L. Meyer, G. Alexander, et al. 2007. Restoring rivers one reach at a time: Results from a survey of U.S. river restoration practitioners. *Restoration Ecology* 15: 482–493.

Blumenfeld, T. 2014. *Resilience in mountainous Southwest China: Adopting a socio= ecological approach to community change*, pp. 281–00.

Blumstein, D.T., and O. Berger-Tal. 2015. Understanding sensory mechanisms to develop effective conservation and management tools. *Current Opinion in Behavioural Sciences* 6: 13–18.

Boon, P.J., P. Calow, and G.E. Petts, eds. 1992. *River conservation and management*, 470 pp. Chichester: Wiley.

Bonetto, A.A. 1994. Austral rivers of South America. In *Limnology now*, ed. R. Margalef, 425–472. Elsevier.

Bornette, G., and A.R.G. Large. 1995. Groundwater-surface water ecotones at the upstream part of confluences in former river channels. *Hydrobiologia* 310: 123–137.

Bowyer, M.W., J.D. Stafford, A.P. Yetter, C.S. Hine, M.M. Horath, and S.P. Havera. 2005. Moist-soil plant seed production for waterfowl at Chautauqua National Wildlife Refuge, Illinois. *American Midland Naturalist* 154: 331–341.

Bradshaw, A.D. 1987. Restoration: An acid test for ecology. In *Restoration ecology. A synthetic approach to ecological research*, ed. W.R. Jordan III, M.E. Gilpin, and J.D. Aber, 23–29. Cambridge: Cambridge University Press.

———. 1993. Restoration ecology as a science. *Restoration Ecology* 1: 71–73.

———. 1997. What do we mean by restoration? In *Restoration ecology and sustainable development*, ed. K.M. Urbanska, N.R. Webb, and P.J. Edwards, 8–14. Cambridge: Cambridge University Press.

Bravard, J.P., C. Amoros, and G. Pautou. 1986. Impact of civil engineering works on the successions of communities in a fluvial system: A methodological and predictive approach applied to a section of the Upper Rhône River, France. *Oikos*: 92–111.

Brenner, F.J. 1990. Mine reclamation: Opportunity for critical habitat development. In *In ecosystem management: Rare species and significant habitats*, 235–238. New York: State Museum Bulletin.

Brierley, G., and K. Fryirs. 2005. *Geomorphology and river management*. Cornwall: Blackwell Publishing.

Brierley, G.J., K.A. Fryirs, D. Outhet, and C. Massey. 2002. Application of the river styles framework to river management programs in New South Wales, Australia. *Applied Geography* 21: 91–122.

Brookes, A. 1985. River channelisation: Traditional engineering methods, physical consequences and alternative practices. *Progress in Physical Geography* 9: 44–73.

———. 1992. Recovery and restoration of some engineered British river channels. In *River conservation and management*, ed. P.J. Boon, P. Calow, and G.E. Petts, 337–352. Chichester: Wiley.

———. 1995a. Challenges and objectives for geomorphology in UK river management. *Earth Surface Processes and Landforms* 20: 593–610.

———. 1995b. River channel restoration: theory and practice. In *Changing river channels*, ed. A. Gurnell and G.E. Petts, 369–388. Chichester: Wiley.

Brookes, A., and F.D. Shields. 1996. *River Channel restoration: Guiding principles for sustainable projects*, 433. Chichester: Wiley.

Brown, J.H. 1995. *Macroecology*. Chicago: University of Chicago Press.

Burken, J.G., and J.L. Schnoor. 1997. Uptake and metabolism of Atrazine by Poplar trees. *Environmental Science and Technology* 31: 1399–1406.

Buijse, A.D., H. Coops, M. Staras, L.H. Jans, G.J. Van Geest, R.E. Grift, and F.C. Roozen. 2002. Restoration strategies for river floodplains along large lowland rivers in Europe. *Freshwater Biology* 47 (4): 889–907.

Cairns, J., Jr. 1993. Is restoration ecology practical ? *Restoration Ecology* 1: 3–7.

———. 1997. Protecting the theory of ecosystem services. *Ecosystem Healtth* 3: 185–194.

Cairns, J., Jr., and J.R. Heckman. 1996. Restoration ecology: The state of an emerging field. *Annual Review of Energy and the Environment* 21 (1): 167–189.

Cairns, A.J., and C.J. Pollock. 1988. Fructan biosynthesis in excised leaves of Lolium temulentum L. II. Changes in fructosyl transferase activity following excision and application of inhibitors of gene expression. *New Phytologist* 109 (4): 407–413.

Cairns, B., M. Mishchenko, L. Travis, and J. Chowdhary. 2001. Reply to comment on "Retrieval of aerosol properties over the ocean using multispectral and multiangle photopolarimetric measurements from the Research Scanning Polarimeter". *Geophysical Research Letters* 28: 3277–3278.

Chakraborty, S.K. 2011. Mangrove Ecosystem of Sundarbans, India: Biodiversity, ecology, threats and conservation. In *Mangroves: Ecology, biology and taxonomy*, ed. James N. Metras, 83–112. New York: NOVA Publisher.

———. 2013. Interactions of environmental variables determining the biodiversity of coastal mangrove ecosystem of West Bengal, India. *The Ecoscan Special Issue* 3: 251–265.

———. 2017. Ecological services on intertidal benthic fauna and the sustenance of coastal wetlands along the Midnapore (East) coast, West Bengal, India. In *Coastal wetlands: Alteration and remediation*, 777–886. Springer.

———. 2018. Bioinvasion and environmental perturbation: Synergistic impact on coastal – Mangrove ecosystems of West Bengal, India. In *Impacts of invasive species on coastal environments: Coast in crisis*, ed. C. Makowski and C. Finkl, 171–245. Springer.

Chakraborty, S.K., S. Giri, G. Chakravarty, and N. Bhattacharya. 2009. Impact of eco-restoration on the biodiversity of Sundarbans Mangrove Ecosystem, India. *Water Air Soil Pollution: Focus* 9: 303–320.

Chakraborty, S.K., A.K. Paul, J. Bandyopadhyay, D. Banerjee, H. Pakhira, S. Middya, S. Jana, P. Sahoo, K. Paria, and K. Bera. 2013. Sustainable water management in the drought prone riverine tracts of south West Bengal. *Journal of Ground Water Studies* 1: 11–34.

Chapman, D.W., and E. Knudsen. 1980. Channelization and livestock impacts on salmonid habitat and biomass in western Washington. *Transactions of the American Fisheries Society* 109: 357–363.

Chen, W. 2017. Environmental externalities of urban river pollution and restoration: A hedonic analysis in Guangzhou (China). *Landscape and Urban Planning* 157: 170–179.

Chiriboga, L., P. Xie, H. Yee, V. Vigorita, D. Zarou, D. Zakim, and M. Diem. 1998. Infrared spectroscopy of human tissue. I. Differentiation and maturation of epithelial cells in the human cervix. *Biospectroscopy* 4 (1): 47–53.

Choi, Y.D., V.M. Temperton, E.B. Allen, and A.P. Grootjans. 2008. Ecological restoration for future sustainability in a changing environment. *Ecoscience* 15 (1): 53–64.

Connell, J.H. 1978. Diversity in tropical rainforests and coral reefs. *Science* 199: 1302–1310.

Copp, G.H. 1997. Microhabitat use of fish larvae and 0+ juveniles in a highly regulated section of the River Great Ouse. *Regulated Rivers: Research and Management* 13: 267–276.

Costa, R., M. Gotz, N. Mrotzek, J. Lottmann, G. Berg, and K. Smalla. 2005. Effects of site and plant species on rhizosphere community structure as revealed by molecular analysis of microbial guilds. *FEMS Microbialogy Ecology* 56 (2): 336–349.

Costanza, R. 1991. *Ecological economics: The science and management of sustainability*. New York: Columbia University Press.

Cowx, I.G., G.A. Wheatley, and A.S. Mosley. 1986. Long-term effects of land drainage works on fish stocks in the upper reaches of a lowland river. *Journal of Environmental Management* 22: 147–156.

Cowx, I.G., and R.L. Welcomme, eds. 1998. *Rehabilitation of rivers for fish*, 204 pp. Oxford: Fishing News Books, Blackwell Science.

Crabtree, A.F., ed. 1984. *Proceedings of the third international symposium on environmental concerns in rights-of-way management*. Mississippi: Mississippi State University.

Crook, D.A., A.I. Robertson, A.J. King, and P. Humphries. 2001. The influence of spatial scale and habitat arrangement on diel patterns of habitat use by two lowland river fishes. *Oecologia* 129: 525–533.
Cunningham, S. 2002. *The restoration economy: The greatest new growth frontier*. New York: Berrett Koehler.
Cushing, D.H. 1990. Plankton production and year-class strength in fish populations: An update of the match/mismatch hypothesis. *Advanced Marine Biology* 26: 249–292.
Dahl, T.E. 1990. *Wetlands losses in the United States 1780s to 1980s*. Washington, DC: U.S. Department of the Interior, Fish and Wildlife Service.
Davies, T., M. Everard, and M. Horswell. 2016. Community-based groundwater and ecosystem restoration in semi-arid North Rajasthan (3): Evidence from remote sensing. *Ecosystem Services* 21: 20–30.
de Bello, F., S. Lavorel, S. Diaz, R. Harrington, J. Cornelissen, R. Bargett, M. Berg, P. Cipriotti, C.K. Feld, D. Hering, P. Martins da Silva, S. Potts, L. Sandin, J.P. Sousa, J. Storkey, D. Wardle, and P.A. Harrison. 2010. Towards an assessment of multiple ecosystem processes and services via functional traits. *Biodiversity and Conservation* 19: 2873–2893.
Diekelman, J., and R. Schuster. 1982. *Natural landscaping: Designing with native plant communities*. New York: McGraw-Hill.
Dollar, E.S.J., C.S. James, K.H. Rogers, and M.C. Thoms. 2007. A framework for interdisciplinary understanding of rivers as ecosystems. *Geomorphology* 89: 147–162.
Drago, E. 1990. Geomorphology of large alluvial rivers: Lower Paraguay and middle Parana. *Interciencia* 15: 145–164.
Dufour, S., and H. Piégay. 2009. From the myth of a lost paradise to targeted river restoration: Forget natural references and focus on human benefits. *River Research and Applications* 25: 568–581.
Dushenkov, V., P.B.A.N. Kumar, H. Motto, and I. Raskin. 1995. Phytoextraction -the use of plants to remove heavy metals from soils. *Environmental Science & Technology* 29: 1239–1245.
Dynesius, M., and C. Nilsson. 1994. Fragmentation and flow regulation of the river systems in the northern third of the world. *Science* 266: 753–762.
Ebersole, J.L., W.J. Liss, and C.A. Frissell. 1997. Restoration of stream habitats in the western United States: restoration as reexpression of habitat capacity. *Environmental Management* 21 (1): 1–14.
Ecke, F., S. Hellsten, J. Köhler, A.W. Lorenz, J. Rääpysjärvi, S. Scheunig, J. Segersten, and A. Baattrup-Pedersen. 2016. The response of hydrophyte growth forms and plant strategies to river restoration. *Hydrobiologia*. https://doi.org/10.1007/s10750-015-2605-6.
Edwards, P.J., J. Kollmann, A.M. Gurnell, G.E. Petts, K. Tockner, and J.V. Ward. 1999. Aconceptual model of vegetation dynamics on gravel bars of a large Alpine river. *Wetlands Ecology Management.* 7: 141–153.
Ehrenfeld, J.G., and L.A. Toth. 1997. Restoration ecology and the ecosystem perspective. *Restoration Ecology* 5: 307–317.
Esarey, D. 1993. *The origin and early history of Emiquon*. Lewistown: Dickson Mounds Museum.
European Commission. 2000. Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 Establishing a Framework for Community Action in the Field of Water Policy. *Official Journal* L 327: 73. 22/12/2000, Brussels.
Fabos. 2004.
Fairweather, P.G. 1999. State of environment indicators of 'river health': Exploring the metaphor. *Freshwater Biology* 41 (2): 211–220.
Falk, D.A. 1990. Discovering the past, creating the future. *Restoration and Management Notes* 8 (2): 71–72.
Fausch, K.D., C.E. Torgersen, C.V. Baxter, and H.W. Li. 2002. Landscapes to riverscapes: Bridging the gap between research and conservation of stream fishes. *Bioscience* 52 (6): 483–498.

Ferreira, L.V., and T.J. Stohlgren. 1999. Effects of river level fluctuation on plant species richness, diversity and distribution in a floodplain forest in Central Amazonia. *Oecologia* 120: 582–587.

Figarski, T., and L. Kajtoch. 2015. Alterations of riverine ecosystems adversely affect bird assemblages. *Hydrobiologia* 744: 287–296.

Fisher, S.G. 1983. Succession in streams. In *Stream ecology: Application and testing of general ecological theory*, ed. J.R. Barnes and G.W. Minshall, 7–27. New York: Plenum Press.

———. 1994. Pattern, process and scale in freshwater ecosystems, some unifying thoughts. In *Aquatic ecology: Scale, pattern and process*, ed. P. Giller, A.G. Hildrew, and D.G. Rafaelli, 575–591. Oxford: Blackwell.

Flecker, A.S. 1996. Ecosystem engineering by a dominant detritivore in a diverse tropical stream. *Ecology* 77: 1845–1854.

Flecker, A.S., B.W. Taylor, E.S. Bernhardt, J.M. Hood, and others. 2002. Interactions between herbivorous fishes and limiting nutrients in a tropical stream ecosystem. *Ecology*, 83: 1831–1844

Flecker, A.S., P.B. Mclntyre, J.W. Moore, J.T. Anderson, B.W. Taylor, and R.O. Hall. 2010. Migratory fishes as material and process subsidies in riverine ecosystems. *American Fisheries Society Symposium* 73: 559–592.

Forbes, S.A., and R.E. Richardson. 1913. Studies on the biology of the upper Illinois River. *Bulletin of the Illinois State Laboratory of Natural History* 9: 481–574.

Forman, R.T.T. 1997. *Land mosaics: The ecology of landscapes and regions*. Cambridge: Cambridge University Press.

Francis, G.R., J.J. Magnuson, H.A. Regier, and D.R. Talhelm, eds. 1979. *Rehabilitating great lakes ecosystems*, 37. Ann Arbor: Great Lakes Fishery Commission Technical Report.

Frissell, C.A., and S.C. Ralph. 1998. Stream and watershed restoration. In *River ecology and management: Lessons from the Pacific coastal ecoregion*, ed. R.J. Naiman and R.E. Bilby. New York: Springer.

Frissell, C.A., W.L. Liss, C.E. Warren, and M.D. Hurley. 1986. A hierarchical framework for stream habitat classification: Viewing streams in a watershed context. *Environmental Management* 10: 199–214.

Fuchs, U., and B. Statzner. 1990. Time scales for the recovery potential of river communities after restoration: Lessons to be learned from smaller streams. *Regulated Rivers: Research and Management* 5: 77–87.

Gann, G.D., and D. Lamb. 2006. *Ecological restoration: A mean of conserving biodiversity and sustaining livelihoods (version 1.1)*. Tucson/Gland: Society for Ecological Restoration International/IUCN.

Gawlik, D.E. 2006. The role of wildlife science in wetland ecosystem restoration: Lessons from the Everglades. *Ecological Engineering* 26: 70–83.

Giller, P.S., and A.A. Myers. 1996. *Disturbance and recovery in ecological systems*. Dublin: Royal Irish Academy.

Gleick, P.H. 2003. Global freshwater resources: Soft-path solutions for the 21st century. *Science* 302: 1524–1528.

Gomez-Pompa, A. 2009. The role of biodiversity scientists in a troubled world. *BioScience* 54: 217–225.

González del Tánago, M., and D. García de Jalón. 2004. Hierarchical classification of rivers: A proposal for eco-geomorphic characterization of Spanish rivers within the European water framework directive. In *Aquatic habitats, analysis and restoration, fifth international symposium on ecohydraulics*, ed. P. Vizcaíno and D. García de Jalón, 205–211. Madrid: IAHR Congress Proceedings.

González del Tánago M, Belletti B, Gurnell AM (2015) Indicators of river system character and dynamics, past and present: Understanding the causes and solutions to river management problems. Aquat Sci, this volume.

Goudie, A. 2006. *The human impact on the natural environment*. 6th ed. Oxford: Blackwell Publishing Ltd.

Gore, J.A., ed. 1985. *The restoration of Rivers and streams*, 280 pp. Stoneham: Butterworth.

Gore, A. 1992. *Earth in the balance: Ecology and the human spirit*. New York: Houghton Mifflin.

Gore, J.A., and F.D. Shields. 1995. Can large rivers be restored? *Bioscience* 45: 142–152.

Göthe, E., A. Timmermann, A. Baattrup-Pedersen, and K. Januschke. 2016. Structural and functional responses of floodplain vegetation to stream ecosystem restoration. *Hydrobiologia*. https://doi.org/10.1007/s10750-015-2401-3.

Goudie, A.S., and N.J. Middleton. 2006. *Desert dust in the global system*. New York: Springer.

Gruszecka-Kosowska, A., and A. Kicińska. 2017. Long-term metal-content changes in soils on the Olkusz Zn–Pb ore-bearing area, Poland. *International Journal of Environmental Research* 11 (3): 359–376.

Guida, R.J., J.W.F. Remo, and S. Secchi. 2016. Tradeoffs of strategically reconnecting rivers to their floodplains: The case of the lower Illinois River. *Science of the Total Environment* 572: 43–55.

Gurnell, A.M., M. Rinaldi, B. Belletti, S. Bizzi, B. Blamauer, G. Braca, A.D. Buijse, M. Bussettini, B. Camenen, F. Comiti, L. Demarchi, D. García de Jalón, M. González del Tánago, R.C. Grabowski, I.D.M. Gunn, H. Habersack, D. Hendriks, A.J. Henshaw, M. Klösch, B. Lastoria, A. Latapie, P. Marcinkowski, V. Martínez-Fernández, E. Mosselman, J.O. Mountford, L. Nardi, T. Okruszko, M.T. O'Hare, M. Palma, C. Percopo, N. Surian, W. van de Bund, C. Weissteiner, and L. Ziliani. 2016. A multi-scale hierarchical framework for developing understanding of river behaviour to support river management. *Aquatic Sciences* 78: 1–16.

Habersack, H.M. 2000. The river-scaling concept (RSC): A basis for ecological assessments. *Hydrobiologia* 422 (423): 49–60.

Hagy, H.M., C. Hine, M. Horath, A. Yetter, R. Smith, and J. Stafford. 2016a. Waterbirds as indicators of floodplain restoration. *Hydrobiologia*. https://doi.org/10.1007/s10750-016-3004-3.

Hagy, H.M., M.M. Horath, A.P. Yetter, C.S. Hine, and R.V. Smith. 2016b. Evaluating tradeoffs between sanctuary for migrating waterbirds and recreational opportunities in a restored wetland complex. *Hydrobiologia* 804 (1): 103–118.

Halder Mallick, P., and S.K. Chakraborty. 2015. Does intra-site connectivity influence the dynamics of zooplankton metacommunity in fhresh water habitats ? *Turkish Journal of Fisheries and Aquatic Sciences* 15: 661–675.

Halder Mallick, P., and S.K. Chakraborty. 2018. Forest, wetland and biodiversity: Revealing multifaceted ecological services from ecorestoration of a degraded tropical landscape. *Ecohydrology and Hydrobiology* 18 (3): 278–296.

Hamilton, S.K., W.M. Lewis Jr., and S.J. Sippel. 1992. Energy sources for aquatic animals in the Orinoco River floodplain: Evidence from stable isotopes. *Oecologia* 89: 324–330.

Hart, D.D. 1983. The importance of competitive interactions within stream populations and communities. In *Stream ecology*, ed. J.R. Barnes and G.W. Minshall. New York: Plenum Press.

Harvey, G.L., N.J. Clifford, and A.M. Gurnell. 2008. Towards an ecologically meaningful classification of the flow biotope for river inventory, rehabilitation, design and appraisal purposes. *Journal of Environmental Management* 88: 638–650.

Hasset, B., M.A. Palmer, S. Bernhardt, S. Smith, J. Carr, and D. Hart. 2005. Status and trends of river and stream restoration in the Chesapeake Bay watershed. *Frontiers in Ecology and the Environment* 3: 259–267.

Hauer, C., U. Pulg, S.E. Gabrielsen, and B.T. Barlaup. 2015. Application of step-backwater modelling for salmonid spawning habitat restoration in Western Norway. *Ecohydrology* 8 (7): 1239–1261.

Heede, B.H., and J.N. Rinne. 1990. Hydrodynamic and fluvial morphologic processes: Implications for fisheries management and research. *North American Journal of Fisheries Management* 10 (3): 249–268.

Hering, D., J. Aroviita, A. Baattrup-Pedersen, K. Brabec, T. Buijse, F. Ecke, N. Friberg, M. Gielczewski, K. Januschke, J. Köhler, B. Kupilas, A.W. Lorenz, S. Muhar, A. Paillex,

M. Poppe, T. Schmidt, S. Schmutz, J. Vermaat, P.F.M. Verdonschot, R.C.M. Verdonschot, C. Wolter, and J. Kail. 2015. Contrasting the roles of section length and instream habitat enhancement for river restoration success: A field study on 20 European restoration projects. *Journal of Applied Ecology* 52: 1518–1527.

Hey, R.D. 1992. River mechanics and habitat creation. In *Fisheries in the year 2000*, ed. K.T. O'Grady, A.J.B. Butterworth, and R.P. Spillet, 271–285. Nottingham: Institute of Fisheries Management.

Higgins, P.T., S. Dobush, and D. Fuller. 1992. *Factors in Northern California threatening stocks with extinction*, 1–25. Arcata: Humboldt Chapter of American Fisheries Society.

Higgs, E.S. 1997. What is good ecological restoration? *Conservation Biology* 11: 338–348.

Higgs, E. 2003. *Nature by design: People, natural process, and ecological restoration*. Cambridge, MA: MIT Press.

Hillman, M., and G. Brierley. 2005. A critical review of catchment-scale stream rehabilitation programmes. *Progress in Physical Geography* 29 (1): 55–70.

Hine, C.S., H.M. Hagy, A.P. Yetter, M.M. Horath, R.V. Smith, and J.D. Stafford. 2016. Response of aquatic vegetation and other wetland cover types to floodplain restoration at Emiquon Preserve. *Hydrobiologia*.

Hobbs, R.J., and V.A. Cramer. 2008. Restoration ecology: Interventionist approaches for restoring and maintaining ecosystem function in the face of rapid environmental change. *Annual Review of Environment and Resources* 33: 39–61.

Hobbs, R.J., and D.A. Norton. 1996. Towards a conceptual framework for restoration ecology. *Restoration Ecology* 4: 93–110.

Holčík, J., I. Bastl, M. Ertl, and M. Vranovský. 1981. Hydrobiology and ichthyology of the Czechoslovak Danube in relation to predicted changes after the construction of the Gabčíkovo-Nagymaros River barrage system. *Práce Lab Rybár Hydrobiol* 3: 19–158.

Holling, C.S. 1973. Resilience and stability of ecological systems. *Annual Review of Ecology and Systematics* 4: 1–23.

Holmes, N.T.H. 1998. *A review of river rehabilitation in the UK, 1990–1996*, Environment Agency R & D Technical Report W175. Norwich: Environment Agency.

Hughes, F.M.R. 1997. Floodplain biogeomorphology. *Progress in Physical Geography* 21: 501–529.

Hughes, F.M.R., N. Barsoum, K.S. Richards, M. Winfield, and A. Hayes. 2000a. The response of male and female black poplar (Populus nigra L. subsp. betulifolia (Pursh) W. Wettst.) cuttings to different water table depths and sediment types: Implications for flow management and river corridor biodiversity. *Hydrological Processes* 14: 3075–3098.

Hughes, R.M., S.G. Paulsen, and J.L. Stoddard. 2000b. EMAP-surface waters: A national, multiassemblage, probability survey of ecological integrity. *Hydrobiologia* 422–423 (15): 429–443.

———. 2000c. EMAP-surface waters: A multiassemblage, probability survey of ecological integrity in the USA. In *Assessing the ecological integrity of running waters*, ed. M. Jungwirth, S. Muhar, and S. Schmutz, 429–433. Dordrecht: Kluwer.

Hughes, S.J., J.M. Santos, M.T. Ferreira, R. Caraça, and A.M. Mendes. 2009. Ecological assessment of an intermittent Mediterranean river using community structure and function: Evaluating the role of different organism groups. *Freshwater Biology* 54: 2383–2400.

Hughes, S.J., J. Santos, T. Ferreira, and A. Mendes. 2010. Evaluating the response of biological assemblages as potential indicators for restoration measures in an intermittent Mediterranean river. *Environmental Management* 46: 285–301.

Ivey, G.L., J.E. Cornely, and B.D. Ehlers. 1998. Carp impacts on waterfowl at Malheur National Wildlife Refuge. In *Transactions of the 63rd North American Wildlife and Natural Resources Conference*. Washington, DC: Wildlife Management Institute. Hydrobiologia (2017) 804:119–137 135.

Jackson, C.R., and C.M. Pringle. 2010. Ecological benefits of reduced hydrologic connectivity in intensively developed landscapes. *Bioscience* 60 (1): 37–46.

Jackson, L.L., N. Lopoukhine, and D. Hillyard. 1995a. Ecological restoration: A definition and comments. *Restoration Ecology* 3: 71–75.

Jackson, P., T. McRae, and M. Hogarth. 1995b. Selection of sugarcane families across variable environments II. Patterns of response and association with environmental factors. *Field Crops Research* 43 (2–3): 119–130.

Jacobson, M.Z. 2001. Strong radiative heating due to the mixing state of black carbon in atmospheric aerosols. *Nature* 409 (6821): 695.

———. 2002. Control of fossil-fuel particulate black carbon and organic matter, possibly the most effective method of slowing global warming. *Journal of Geophysical Research: Atmospheres* 107 (D19): ACH-16.

Jansson, R., H. Backx, A.J. Boulton, M. Dixon, D. Dudgeon, F.M.R. Hughes, K. Nakamura, E.H. Stanley, and K. Tockner. 2005. Stating mechanisms and refining criteria for ecologically successful river restoration: A comment on Palmer et al. (2005). *Journal of Applied Ecology* 42: 218–222.

Jansson, R., C. Nilsson, and B. Malmqvist. 2007. Restoring freshwater ecosystems in riverine landscapes: The roles of connectivity and recovery processes. *Freshwater Biology* 52: 589–596.

Jenkins, Merchant, Nankivil, and W.B. Walraven. 1950. *Survey and report on potential conservation areas along the Illinois River from Hennepin to Grafton*. Illinois Department of Conservation, State of Illinois.

Johnson, M.D. 2000. Evaluation of an arthropod sampling technique for measuring food availability for forest insectivorous birds. *Journal of Field Ornithology* 71: 88–109.

Jones, C.G., J.H. Lawton, and M. Shachak. 1994. Organisms as ecosystem engineers. *Oikos* 69: 373–386.

Jones, C., J. Lawton, and M. Shachak. 1997. Positive and negative effects of organisms as physical ecosystems engineers. *Ecology* 78: 1946–1957.

Jordan, W.R., III, M.E. Gilpin, and J.D. Aber. 1987. *Restoration ecology. A synthetic approach to ecological research*. Cambridge: Cambridge University Press.

Jungwirth, M., O. Moog, and S. Muhar. 1993. Effects of river bed restructuring on fish and benthos of a fifth order stream, Melk, Austria. *Regulated Rivers: Research and Management* 8: 195–204.

Jungwirth, M., S. Muhar, and S. Schmutz. 2002. Reestablishing and assessing ecological integrity in riverine landscapes. *Freshwater Biology* 47 (4): 867–888.

Junk, W.J., and K.M. Wantzen. 2004. The flood pulse concept: New aspects, approaches, and applications—An update. In *Proceedings of the second international symposium on the management of large rivers for fisheries*, ed. R.L. Welcomme and T. Petr, vol. 2. Food and Agriculture.

Junk, W.J., P.B. Bayley, and R.E. Sparks. 1989. The flood-pulse concept in river-floodplain systems. In *Proceedings of the international large river symposium (LARS)*, Canadian special publication in fisheries and aquatic sciences, 106, ed. D.P. Dodge.

Kajtoch, L., M. Zmihorski, and A. Piestrzynska-Kajtoch. 2014. The goosander as potential indicator of naturalness and biodiversity in submontane river valleys of northern Carpathians. *Ecological Indicators* 45: 83–92.

Kapoor, A., T. Viraraghavan, and D.R. Cullimore. 1999. Removal of heavy metals using the fungus Aspergillus niger. *Bioresource Technology* 70: 95–104.

Karr, J.R., and E.W. Chu. 1999. *Restoring life in running waters: Better biological monitoring*. Washington, DC: Island Press.

Keddy, P.A. 1983. Shoreline vegetation in Axe Lake, Ontario: Effects of exposure on zonation patterns. *Ecology* 64: 331–344.

Kern, K. 1992. Rehabilitation of streams in South-West Germany. In *River conservation and management*, ed. P.J. Boon, P. Calow, and G.E. Petts, 321–336. Chichester: Wiley.

Kieft, T.L. 1991. Soil microbiology in reclamation of arid and semiarid lands. In *Semiarid lands and deserts: Soil resource and reclamation*, ed. J. Skujins, 209–256. New York: Marcel Dekker.

Kim, J., S.B. Verma, and D.P. Billesbach. 1998. Seasonal variation in methane emission from a temperate Phragmitesdominated marsh: Effect of growth stage and plant-mediated transport. *Global Change Biology* 5: 443–440.

Kim, H.Y., M. Lieffering, S. Miura, K. Kobayashi, and M. Okada. 2001. Growth and nitrogen uptake of C02-enriched rice under field conditions. *New Phytologist* 150: 223–229.

Kondolf, G.M. 2011. Setting goals in river restoration: When and where can the river "heal itself"? In *Stream restoration in dynamic fluvial systems: Scientific approaches, analyses, and tools*, ed. A. Simon, S.J. Bennett, and J.M. Castro. Washington, DC: American Geophysical Union.

Kondolf, G.M., and M. Larson. 1995. Historical channel analysis and its application to riparian and aquatic habitat restoration. *Aquatic Conservation: Marine and Freshwater Ecosystems* 5 (2): 109–126.

Kondolf, G.M., D.R. Montgomery, H. Piegay, and L. Schmitt. 2003. Geomorphic classification of rivers and streams. In *Tools in fluvial geomorphology*, ed. G.M. Kondolf and H. Piegay, 171–204. Chichester: Wiley.

Kondolf, G.M., A.J. Boulton, S. O'Daniel, et al. 2006. Process-based ecological river restoration: Visualizing three-dimensional connectivity and dynamic vectors to recover lost linkages. *Ecology and Society* 11 (2).

Kumar, P., V. Dushenkov, H. Motto, and I. Raskin. 1995. Phytoextraction: The use of plants to remove heavy metals from soils. *Environmental Science & Technology* 29: 1232–1238.

Kupilas, B., N. Friberg, B.G. McKie, M.A. Jochmann, A.W. Lorenz, and D. Hering. 2016. River restoration and the trophic structure of benthic invertebrate communities across 16 European restoration projects. *Hydrobiologia*. https://doi.org/10.1007/s10750-015-2569-6.

Kushner, D.J. 1978. Life in high salt and solute concentrations. In *Microbial life in extreme environments*, ed. D.J. Kushner, 317–368. London: Academic.

Lal, B.B., M. Diem, P.L. Polavarapu, M. Oboodi, T.B. Freedman, and L.A. Nafie. 1982. Vibrational circular dichroism in amino acids and peptides. 5. Carbon-hydrogen, stretching vibrational circular dichroism and fixed partial charge calculations for deuterated isotopomers of alanine. *Journal of the American Chemical Society* 104 (12): 3336–3342.

Latour, R.J., E.J. Hilton, P.D. Lynch, T.D. Tuckey, B.E. Watkins, and J.E. Olney. 2012. Evaluating the current status of American shad (Alosa sapidissima) stocks in Virginia. *Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science* 4: 302–311.

Lehner, B., C.R. Liermann, C. Revenga, C. Vorosmarty, B. Fekete, P. Crouzet, P. Doll, M. Endejan, K. Frenken, J. Magome, C. Nilsson, J.C. Robertson, R. Rodel, N. Sindorf, and D. Wisser. 2011. High-resolution mapping of the world's reservoirs and dams for sustainable river-flow management. *Frontiers in Ecology and the Environment* 9: 494–502.

Lemke, A.M., J.R. Herkert, J.W. Walk, and K.D. Blodgett. 2017a. Application of Key Ecological Attributes to assess early restoration of river floodplain habitats: A case study. *Hydrobiologia*. https://doi.org/10.1007/s10750-017-3261-9.

Lemke, M.J., H.M. Hagy, A.F. Casper, and H. Chen. 2017b. Floodplain wetland restoration along the Illinois River. In *Ecological restoration in the Midwest: Building on the legacy*, ed. C. Lenhart and P.C. Smiley Jr. Iowa City: University of Iowa Press.

Lemke, M.J., S.F. Paver, K. Dungey, F.M. Velho, A. Kent, L.C. Rodrigues, D.M. Kellerhals, and M. Randle. 2017c. Diversity and succession of pelagic microorganism communities in a newly restored Illinois River floodplain lake. *Hydrobiologia*. https://doi.org/10.1007/s10750-017-3327-8.

Lemke, M.J., H.M. Hagy, K.E. Dungey, A.F. Casper, A.M. Lemke, T.D. VanMiddlesworth, and A. Kent. 2017d. Echoes of a flood pulse: Shortterm effects of record flooding of the Illinois River on floodplain lakes under restoration. *Hydrobiologia*. https://doi.org/10.1007/s10750-017-3220-5.

Lemons, J., and D.A. Brown, eds. 1995. *Sustainable development: Science, ethics and public policy*. Dordrecht: Kluwer Academic Publishers.

Light, A., and E.S. Higgs. 1996. The politics of ecological restoration. *Environmental Ethics* 18: 227–248.

Loegering, J.P., and J.D. Fraser. 1995. Piping plover survival in different brood-rearing habitats. *Journal of Wildlife Management* 59: 646–655.

Lyons, J.E. 2005. Habitat specific foraging of Prothonotary warblers: Deducing habitat quality. *Condor* 107: 41–49.

MacMahon, J.A. 1987. Empirical and theoretical ecology as a basis for restoration: An ecological success story. *Success, Limitation and Frontiers in Ecosystem Science, pp*: 220–246.

Maddock, I. 1999. The importance of physical habitat assessment for evaluating river health. *Freshwater Biology* 41 (2): 373–391.

Mann, R.H.K. 1988. Fish and fisheries of regulated rivers in the U.K. *Regulated Rivers: Research and Management* 2: 411–424.

Mason, N.W.H., P. Irz, C. Lanoiselee, D. Mouillot, and C. Argillier. 2008. Evidence that niche specialization explains species–energy relationships in lake fish communities. *Journal of Animal Ecology* 77: 285–296.

Mayer, P.M., E. Striz, R. Shedlock, E. Doheny, and P. Groffman. 2003. The effects of ecosystem restoration on nitrogen processing in an urban mid-Atlantic piedmont stream. In *First interagency conference on research in the watersheds, October 27–30, 2003*, ed. K.G. Renard, S.A. McElroy, W.J. Gburek, H.E. Canfield, and R.L. Scott, 536–541. Washington, DC: US Department of Agriculture, Agricultural Research Service.

McCluney, K.E., N.L. Poff, M.A. Palmer, J.H. Thorp, G.C. Poole, B.S. Williams, M.R. Williams, and J.S. Baron. 2014. Riverine macrosystems ecology: Sensitivity, resistance, and resilience of whole river basins with human alterations. *Frontiers in Ecology and the Environment* 12: 48–58.

McElhinny, C. 2002. *Forest and woodland structure as an index of biodiversity: A review*. Canberra: Department of Forestry, Australian National University.

Millennium Ecosystem Assessment (MEA). 2005. *Ecosystems and human well-being*. Washington, DC: Island Press.

Milner, A.M., and G.E. Petts. 1994. Glacial rivers: Physical habitat and ecology. *Freshwater Biology* 32 (2): 295–307.

Mishra, T.K., and S.B. Roy. 2002. *Sustainability of soil and vegetation under community managed forests: A case study from Southwest Bengal*. In 12th ISCO conference, Beijing. http://www.tucson.ars.ag.gov/isco/isco12/VolumeIII/SustainabilityofSoilandVegetation.pdf

Mitsch, W.J. 1993. Ecological engineering: A cooperative role with the planetary life-support system. *Environmental Science and Technology* 27: 438–445.

Montgomery, D.R., and J.M. Buffington. 1997. Channel-reach morphology in mountain drainage basins. *Geological Society of America Bulletin* 109: 596–611.

———. 1998. Channel processes, classification, and response. In *River ecology and management: Lessons from the Pacific coastal ecoregion*, ed. R.J. Naiman and R.E. Bilby, 13–42. New York: Springer.

Montgomery, D.R., and L.H. MacDonald. 2002. Diagnostic approach to stream channel assessment and monitoring. *Journal of the American Water Resources Association* 38: 1–16.

Morris, S.E. 1995. Geomorphic aspects of stream-channel restoration. *Physical Geography* 16: 444–459.

Morrison, M.I. 1986. Bird populations as indicators of environmental change. In *Current ornithology*, ed. R.F. Johnston, 429–451. New York: Plenum. North American Waterfowl Management Plan (NAWMP), 2012. North American waterfowl management plan: People conserving waterfowl and wetlands.

Muhar, S. 1996. Habitat improvement of Austrian rivers with regard to different spatial scales. *Regulated Rivers: Research & Management* 12: 471–482.

Muotka, T., and P. Laasonen. 2002. Ecosystem recovery in restored headwater streams: The role of enhanced leaf retention. *Journal of Applied Ecology* 39: 145–156.

Naiman, R.J., and H. De'camps. 1997. The ecology of interfaces: Riparian zones. *Annual Review of Ecology and Systematics* 28: 621–658.

Naiman Robert, J., and Robert E. Bilby. 1998. *River ecology and management lessons from the Pacific coastal ecoregion*. New York: Springer.

Naiman, R.J., D.G. Lonzarich, T.J. Beechie, and S.C. Ralph. 1992. General principles of classification and the assessment of conservation in rivers. In *River conservation and management*, ed. P.J. Boon, P. Calow, and G.E. Petts, 93–123. Washington, DC: American Geophysical Union.

National Research Council. 1992. *Restoration of aquatic ecosystems: Science, technology and public policy*. Washington, DC: National Academy Press.

Newbury, R., and M. Gaboury. 1993. Exploration and rehabilitation of hydraulic habitats in streams using principles of fluvial behaviour. *Freshwater Biology* 29 (2): 195–210.

Niemi, G.J., P. DeVore, N. Detenbeck, D. Taylor, A. Lima, J. Pastor, and R.J. Naiman. 1990. Overview of case studies on recovery of aquatic systems from disturbance. *Environmental Management* 14 (5): 571–587.

Niemi, G.J., P. DeVore, N. Detenbeck, D. Taylor, J.D. Yount, A. Lima, R.J. Pastor, and R.J. Naiman. 1990. Overview of case studies on recovery of aquatic systems from disturbance. *Environmental Management* 14: 571–588.

Niemi, G.J., J.M. Hanowski, A.R. Lima, T. Nicholls, and N. Wiland. 1997. A critical analysis on the use of indicator species in management. *Journal of Wildlife Management* 61: 1240–1252.

Nilsson, C., M. Gardfjell, and C. Grelsson. 1991. Importance of hydrochory in structuring plant communities along rivers. *Canadian Journal of Botany* 69: 2631–2633.

Nilsson, C., C.A. Reidy, M. Dynesius, and C. Revenga. 2005. Fragmentation and flow regulation of the world's large river systems. *Science* 308: 405–408.

NRC (National Research Council). 1992. *Restoration of aquatic ecosystems*. Washington, DC: National Academy Press.

Omerod, P., and A.P. Roach. 2004. The medieval inquisition: Scale-free networks and the suppression of heresy. *Physica A: Statistical Mechanics and its Applications* 339 (3–4): 645–652.

Ormerod, S.J. 2003. Restoration in applied ecology: Editor's introduction. *Journal of Applied Ecology* 40: 44–50.

Ostfeld, R.S., S.T.A. Pickett, M. Shachak, and G.E. Likens. 1997. Defining the scientific issues. In *The ecological basis of conservation*, 3–10. Boston: Springer.

Pahl-Wostl, C., M. Craps, A. Dewulf, E. Mostert, D. Tabara, and T. Taillieu. 2007. Social learning and 565 water resources management. *Ecology and Society* 12 (2): 5. [online] URL: 566 http://www.ecologyandsociety.org/vol12/iss2/art5/.

Palmer, M.A. 1997. Biodiversity and ecosystem processes in freshwater sediments. *Ambio* 26 (8): 571–577.

———. Socioenvironmental sustainability. Standardsfor ecologically successful river restoration. *Journal of Applied Ecology* 42: 208–217. andactionable science. Bioscience 2012, 62:5–6.

Palmer, M.A., and J.D. Allan. 2006. Restoring rivers. *Issues in Science and Technology* 22: 40–48.

Palmer, M.A., and N.L. Poff. 1997. Heterogeneity in streams: The influence of environmental heterogeneity on patterns and processes in streams. *Journal of the North American Benthological Society* 16: 169–173.

Palmer, Margaret, Richard Ambrose, and N. Poff. 1997. Ecological theory and community restoration ecology. *Restoration Ecology* 5: 291–300.

Palmer, M.A., E.S. Bernhardt, J.D. Allan, P.S. Lake, G. Alexander, S. Brooks, J. Carr, S. Clayton, C. Dahm, J. Follstad Shah, D.J. Galat, S. Gloss, P. Goodwin, D.H. Hart, B. Hassett, R. Jenkinson, G.M. Kondolf, R. Lave, J.L. Meyer, T.K. O'Donnell, L. Pagano, P. Srivastava, and E. Sudduth. 2005. Standards for ecologically successful river restoration. *Journal of Applied Ecology* 42: 208–217.

Palmer, M.A., D.L. Strayer, and S.D. Rundle. 2007. Meiofauna. In *Methods in stream ecology*, ed. F.R. Hauer and G.A. Lamberti, 415–433. Burlington: Academic (Elsevier).

Paria, K., S.M. Mandal, and S.K. Chakroborty. 2017. Simultaneous removal of Cd(II) and Pb (II) using a fungal isolate, Aspergillus penicillioides (F12) from Subarnarekha Estuary. *International Journal of Environmental Research* 12 (1): 77–86.

Parker, V.T. 1997. The scale of successional models and restoration objectives. *Restoration Ecology* 5: 301–306.

Parrish, J.D., D.P. Braun, and R.S. Unnasch. 2003. Are we conserving what we say we are? Measuring ecological integrity within protected areas. *BioScience* 53: 851–860.

Pearsons, T.N., H.W. Li, and G.A. Lamberti. 1992. Influence of habitat complexity on resistance to flooding and resilience of stream fish assemblages. *Transactions of the American Fisheries Society* 121: 427–436.

Pollock, M.M., R.J. Naiman, and T.A. Hanley. 1998. Plant species richness in riparian wetlands: A test of biodiversity theory. *Ecology* 79: 94–105.

Pollock, M.M., T.J. Beechie, and C.E. Jordan. 2007. Geomorphic changes upstream of beaver dams in Bridge Creek, an incised stream channel in the interior Columbia River basin, Eastern Oregon. *Earth Surface Processes and Landforms* 32: 1178–1185.

Poppe, M., J. Kail, J. Aroviita, M. Stelmaszczyk, M. Giełczewski, and S. Muhar. 2016. Assessing restoration effects on hydromorphology in European mid-sized rivers by key hydromorphological parameters. *Hydrobiologia* 769: 21–40.

Pradhan, P., and S.K. Chakraborty. 2008. Ecological study of rotifera and its application for biomonitoring freshwater riverine environment. In *Zoological research in human welfare*, 289–306. Kolkata): Paper-31: Zoological Society of India.

Pradhan, P., S.S. Mishra, R. Majumder, and S.K. Chakraborty. 2003. Environmental monitoring with special emphasis on bio-monitoring – A prerequisite for sustainable environmental management: A case study in Darwakeswar river of South West Bengal, India. In *Environment pollution and management*, ed. A. Kumar, C. Bhora, and L.K. Sing, 87–103. New Delhi: Ashish Publishing Corporation.

Punchard, N.T., M.R. Perrow, and A.J.D. Jowitt. 2000. Structure, density and biomass in natural and channelised lowland streams in the catchment of the River Wensum, UK. In *Management and ecology of river fisheries*, ed. I.G. Cowx, 143–157. Oxford: Fishing News Books.

Rapport, D.J. 1989. What constitutes ecosystem health? *Perspectives in Biology and Medicine* 33: 120–132.

Raskin, I., and B.T. Ensley. 2000. *Phytoremediation of toxic metals -using plants to clean up the environment*, ix. New York: Wiley Inter-Science Publication.

Reuter, M., K. Lubinski, P. West, D. Blodgett, and M. Khoury. 2005. The nature conservancy's approach to conserving and rehabilitating biological diversity in the Upper Mississipi River system. *Large Rivers* 15: 549–560.

Ricciardi, A., and J.B. Rasmussen. 1999. Extinction rates of North American freshwater fauna. *Conservation Biology* 13 (5): 1220–1222.

Richardson, R.E. 1928. The bottom fauna of the middle Illinois River, 1913-1925; Its distribution, abundance, valuation, and index valve in the study of stream pollution. *Illinois Natural History Survey Bulletin* 17 (12): 387–475.

Richards, J.A., and J.A. Richards. 1999. *Remote sensing digital image analysis*. Vol. 3. Heidelberg/Berlin/New York: Springer.

Richards, K., J. Brasington, and F. Hughes. 2002. Geomorphic dynamics of floodplains: Ecological implications and a potential modelling strategy. *Freshwater Biology* 47: 559–579.

Riley, A.L. 1998. *Restoring streams in cities: A guide for planners, policymakers, and citizens*. Washington, DC: Island Press.

Riley, S.C., and K.D. Fausch. 1995. Trout population response to habitat enhancement in six northern Colorado streams. *Canadian Journal of Fisheries and Aquatic Science* 52: 34–53.

Rinaldi, M., N. Surian, F. Comiti, and M. Bussettini. 2013. A method for the assessment and analysis of the hydromorphological condition of Italian streams: The morphological quality index (MQI). *Geomorphology* 180–181: 96–108.

———. 2015a. A methodological framework for hydromorphological assessment, analysis and monitoring (IDRAIM) aimed at promoting integrate driver management. *Geomorphology*. https://doi.org/10.1016/j.geomorph.2015.05.010.

Rinaldi M, Gurnell AM, González del Tánago M, Bussettini M, Hendriks D (2015b) Classification and characterization of river morphology and hydrology to support management and restoration. Aquat Sci, this volume.

Robertson, A.I., P. Bacon, and G. Heagney. 2001. The responses of floodplain primary production to flood frequency and timing. *Journal of Applied Ecology* 38: 126–136.

Roni, P., T.J. Beechie, R.E. Bilby, F.E. Leonetti, M.M. Pollock, and G.R. Pess. 2002. A review of stream restoration techniques and a hierarchical strategy for prioritizing restoration in Pacific Northwest watersheds. *North American Journal of Fisheries Management* 22: 1–20.

Roni, P., T. Beechie, S. Schmutz, and S. Muhar. 2013. Prioritization of watersheds and restoration projects. In *Stream and watershed restoration – A guide to restoring riverine processes and habitats*, ed. P. Roni and T. Beechie. Hoboken: Wiley.

Rolston H (III). 1988. *Environmental ethics, Dutiesto and values in the natural world*. Philadelphia: Temple University Press.

Rosenzweig, M.L. 1987. Restoration ecology: A tool to study population interactions. In *Restoration ecology: A synthetic Appraoch to ecological research*, ed. W.R. Jordan, M.E. Gilpin, and J. D. Aber. New York: Cambridge University Press.

Rosgen, D.L. 1994. A classification of natural rivers. *Catena* 22: 169–199.

RRC. 1999. *Manual of river restoration techniques*. Silsoe: River Restoration Centre.

Sanyal, P., S.K. Chakraborty, and P.B. Ghosh. 2014. Phytoremediation of sewage-fed wetlands of East-Kolkata, India: A case study. *International Research Journal of Environmental Sciences* 4 (1): 80–89.

Schiemer, F., T. Spindler, H. Wintersberger, A. Schneider, and A. Chovanec. 1991. Fish fry associations: Important indicators for the ecological status of large rivers. *International Vereiningung fuer Theoretische und Angewandte Limnologie Verhandlungen* 24: 2497–2500.

Schinegger, R., C. Trautwein, A. Melcher, and S. Schmutz. 2012. Multiple human pressures and their spatial patterns in European running waters. *Water and Environment Journal* 26: 261–273.

Schmutz, S., P. Jurajda, S. Kaufmann, A.W. Lorenz, S. Muhar, A. Paillex, M. Poppe, and C. Wolter. 2016. Response of fish assemblages to hydromorphological restoration in central and northern European rivers. *Hydrobiologia*. https://doi.org/10.1007/s10750-015-2354-6.

Schneider, R.L., and R.R. Sharitz. 1988. Hydrochory and regeneration in a bald cypress-water tupelo swamp forest. *Ecology* 69: 1055–1063.

Sear, D.A. 1994. River restoration and geomorphology. *Aquatic Conservation* 4: 169–177.

Sendzimir, J., P. Magnuszewski, Z. Flachner, P. Balogh, G. Molnar, A. Sarvari, and Z. Nagy. 2008. Assessing the resilience of a river management regime: Informal learning in a shadow network in the Tisza River Basin. *Ecology and Society* 13 (1): 11.

S.E.R (Society for Ecological Restoration). 1996. *Ecological restoration: Definitions*. http://www.ser.org.

SER (Society for Ecological Restoration) International Science & Policy Working Group. 2004. *The SER international primer on ecological restoration*. Tucson: Society for Ecological Restoration International. Retrieved from: http://www.ser.org. Accessed July 2005.

Silverstein, R.M., G.C. Bassler, and T.C. Morril. 1991. *Spectrometric identification of organic compounds*. 5a ed. Hoboken: Wiley, EEUU.

Singh, P.P. 2008. Exploring biodiversity and climate change benefits of community-based forest management. *Global Environmental Change* 18: 468–478.

Slocombe, D.S. 1998. Defining goals and criteria for ecosystem based management. *Environmental Management* 22: 483–493.

Smith, R.L. 1996. *Ecology and field ecology*, 1–740. Menlo Park: Addison-Wesley Educational Publishers.

Sparks, R.E. 1995. Need for ecosystem management of large rivers and their floodplains. *Bioscience* 45: 168–182.

Sparks, R.E., P.B. Bayley, S.L. Kohler, and L.L. Osborne. 1990. Disturbance and recovery of large floodplain rivers. *Environmental Management* 14: 699–709.

Stafford, J.D., M.M. Horath, A.P. Yetter, C.S. Hine, and S.P. Havera. 2007. Wetland use by mallards during spring and fall in the Illinois and Central Mississippi River Valleys. *Waterbirds* 30: 394–402.

Stolen, E.D., D.R. Breininger, and P.C. Frederick. 2005. Using waterbirds as indicators in Estuarine systems: Successes and perils. In *Estuarine indicators*, ed. S.A. Bortone, 409–422. Boca Raton: CRC Press.

Straub, J.N. 2008. *Energetic carrying capacity of habitats used by spring-migrating waterfowl in the upper Mississippi River and Great Lakes region*. Columbus: Ohio State University. 136 Hydrobiologia (2017) 804:119–137.

Suding, K.N., K.L. Gross, and D.R. Housman. 2004. Alternative states and positive feedbacks in restoration ecology. *Trends in Ecology and Evolution* 19: 46–53.

Sullivan, K., T.E. Lisle, E.A. Dolloff, G.E. Grant, and L.M. Reid. 1987. Stream channels: The link between forests and fishes. In *Streamside management: Forestry and fishery interactions*, Institute of Forest Resources Contribution Number 57, ed. Salo and T.W. Cundy, 39–97. Washington, DC: University of Washington, Seattle, Seattle.

Swales, S. 1989. The use of instream habitat improvement methodology in mitigating the adverse effects of river regulation on fisheries. In *Alternatives in regulated river management*, ed. J.A. Gore and G.E. Petts, 186–208. Boca Raton: CRC Press Inc.

Sweeney, S. 2000. *Restoration of the environment: Social movement, adaptive culture, emerging science*. Olomouc: University of Olomouc Press.

Taylor, E.B. 1999. Species pairs of north temperate freshwater fishes: Evolution, taxonomy, and conservation.

Taylor, S.G. 2007. Climate warming causes phenological shift in Pink Salmon, *Oncorhynchus gorbuscha*, behavior at Auke Creek, Alaska. *Global Change Biology* 14: 229–235.

The Nature Conservancy (TNC). 2006. *Key attributes and indicators for Illinois River conservation targets at The Nature Conservancy's Emiquon Preserve*. Peoria: The Nature Conservancy.

Thompson, D.H. 1928. The "knothead" carp of the Illinois River. *Illinois Natural History Survey Bulletin* 17 (8): 285–320.

Thompson, D., and G. Stull. 2002. The development and historic use of habitat structures in channel restoration in the United States: The grand experiment in fisheries management. *Géographie Physique et Quaternaire* 56 (1): 45–60.

Thorp, J.H., M. Thoms, and M.D. Delong. 2006. The riverine ecosystem synthesis: Biocomplexity in river networks across space and time. *River Research and Applications* 22: 123–147.

Tockner, K., and J.A. Stanford. 2002. Riverine flood plains: Present state and future trends. *Environmental Conservation* 293: 308–330.

Tockner, K., F. Schiemer, and J.V. Ward. 1998. Conservation by restoration: The management concept for a river-floodplain system on the Danube River in Austria. *Aquatic Conservation: Marine and Freshwater Ecosystems* 8: 71–86.

Tockner, K., F. Schiemer, C. Baumgartner, G. Kum, E. Weigand, I. Zweimüller, and J.V. Ward. 1999. The Danube restoration project: Species diversity patterns across habitat gradients in the floodplain system. *Regulated Rivers: Research and Management* 15: 245–258.

Tockner, K., F. Malard, and J.V. Ward. 2000. An extension of the flood pulse concept. *Hydrological Processes* 14: 2861–2883.

Townsend, C.R., and A.G. Hildrew. 1994. Species traits in relation to a habitat temple for river systems. *Freshwater Biology* 31: 265–276.

Trollope, D.R., and B. Evans. 1976. Concentrations of coppers, iron, lead, nickel and zinc in freshwater algal blooms. *Environmental Pollution* 11: 109–116.

Turner, B.L., D. Skole, S. Sanderson, G. Fischer, L. Fresco, and R. Leemans. 1995. Land-use and land-cover change: Science/research plan. In *Unknown host publication title*, Report, 35, UN Water 2009. Stockholm: International Geosphere-Biosphere Programme.

van der Valk, A.G., and C.B. Davis. 1978. The role of seed banks in the vegetation dynamics of prairie glacial marshes. *Ecology* 59: 322–335.

van Diggelen, R. 2006. Landscape: Spatial interactions. In *Restoration ecology*, ed. J. van Andel and J. Aronson, 31–44. Oxford: Blackwell.

Vangronsveld, J., J. Colpaert, and K. van Tichelen. 1996. Reclamation of a bare industrial area contaminated by by non-ferrous metals: In situ metal immobilization and revegetation. *Environmental Pollution* 87: 51–59.

VanMiddlesworth, T.D., N.N. Michaels, and A.F. Casper. 2014. The nature conservancy's Emiquon preserve fish and aquatic vegetation monitoring 6-year (2007–2012) report. *INHS Technical Report* 01.

VanMiddlesworth, T.D., N.N. McClelland, G.G. Sass, A.F. Casper, T.W. Spier, and M.J. Lemke. 2016a. Fish community succession and biomanipulation to control two common aquatic ecosystem stressors during a large-scale floodplain lake restoration. *Hydrobiologia*. https://doi.org/10.1007/s10750-016-2696-8.

VanMiddlesworth, T.D., G.G. Sass, B.A. Ray, T.W. Spier, J.D. Lyons, N.N. McClelland, and A.F. Casper. 2016b. Food habits and relative abundances of native piscivores: Implications for controlling common carp. *Hydrobiologia*. https://doi.org/10.1007/s10750-016-2866-8.

Verdonschot, R.C.M., J. Kail, B.G. McKie, and P.F.M. Verdonschot. 2016. The role of benthic microhabitats in determining the effects of hydromorphological river restoration on macroinvertebrates. *Hydrobiologia* 769 (1): 55–66.

Vermaat, J., A.J. Wagtendonk, R. Brouwer, O. Sheremet, E. Ansink, T. Brockhoff, M. Plug, S. Hellsten, J. Aroviita, L. Tylec, M. Gielczewski, L. Kohut, K. Brabec, J. Haverkamp, M. Poppe, K. Boeck, M. Coerssen, J. Segersten, and D. Hering. 2016. Assessing the societal benefits of river restoration using the ecosystem services approach. *Hydrobiologia*. https://doi.org/10.1007/s10750-015-2482-z.

Vörösmarty, C.J., P.B. McIntyre, M.O. Gessner, D. Dudgeon, A. Prusevich, P. Green, et al. 2010. Global threats to human water security and river biodiversity. *Nature* 467 (7315): 555.

Walling, D.E., and P.D. Bates, eds. 1990. *Floodplain processes*, 535–551. Chichester: Wiley.

Waples, R.S., T.J. Beechie, and G.R. Pess. 2009. Evolutionary history, habitat disturbance regimes, and anthropogenic changes: What do these mean for resilience of Pacific salmon populations? *Ecology and Society* 14: 3. http://www.ecologyandsociety.org/vol14/iss1/art3/.

Ward, J.V., and K. Tockner. 2001. Biodiversity: Towards a unifying theme for river ecology. *Freshwater Biology* 46: 807–819.

Welcomme, R.L. 1985. *River fisheries FAO*, Fisheries Technical Paper No.262. Rome: UN Food and Agriculture Organization.

Westra, L. 1995. Ecosystem integrity and sustainability: The foundational value of the wild. In *Perspectives on ecological integrity*, ed. L. Westra and J. Lemons, 12–33. Dordrecht: Kluwer Academic Publishers.

Wetzel, R.G. 2001. *Limnology: Lake and river ecosystems*. 3rd ed. Nova York: Elsevier.

White, R.J. 1996. Growth and development of North American stream habitat management for fish. *Canadian Journal of Fisheries and Aquatic Sciences* 53: 342–363.

Wiant, M.D., and A. Berkson. 2004. The Archaic period. In *Discover Illinois archaeology*, ed. M. D. Wiant and A. Berkson, 6–7. Champaign: Illinois Association for Advancement of Archaeology and the Illinois State Archaeological Survey.

Wiberg-Larsen, P. 1999. Macroinvertebrate biodiversity in restored freshwater habitats – The importance of dispersal. In *Biodiversity in benthic ecology. Proceedings from Nordic Benthological meeting, Silkeborg, 13–14 November 1997*, NERI Technical Report 266, ed. N. Friberg and J.D. Carl, 39–45. Denmark: National Environmental Research Institute.

Wiens, J.A. 2002. Riverine landscapes: Taking landscape ecology into the water. *Freshwater Biology* 47: 501–515.

Winemiller, K.O. 1990. Spatial and temporal variation in tropical fish trophic networks. *Ecological Monographs* 60: 331–367.

———. 2004. Floodplain river food webs: Generalizations and implications for fisheries management. In *Proceedings of the second international symposium on the Management of Large Rivers for fisheries*, ed. R.L. Welcomme and T. Petr, vol. 2. Food and Agriculture.

———. 2007. Interplay between scale, resolution, life history and food web properties. In *From energetics to ecosystems: The dynamics and structure of ecological systems*, ed. K. McCann, D. Noakes, and N. Rooney, 101–126. Dordrecht: Springer.
Winemiller, K.O., and D.B. Jepsen. 1998a. Effects of seasonality and fish movement on tropical river food webs. *Journal of Fish Biology* 53: 267–296.
———. 1998b. Effects of seasonality and fish movement on tropical river food webs. *Journal of Fish Biology* 53 (Supp A): 267–296.
———. 2004. Migratory Neotropical fish subsidize food webs of oligotrophic black- water rivers. In *Food webs at the landscape level*, ed. G.A. Polis, M.E. Power, and G.R. Huxel, 115–132. Chicago: University of Chicago Press.
Winemiller, K.O., J.V. Montoya, C.A. Layman, D.L. Roelke, and J.B. Cotner. 2006. Experimental demonstrations of seasonal fish effects on benthic ecology of a Neotropical floodplain river. *Journal of the North American Benthological Society* 25: 250–262.
Wisheu, I.C., and P.A. Keddy. 1989. The conservation and management of a threatened coastal plain plant community in eastern North America (Nova Scotia, Canada). *Biological Conservation* 48: 229–238.
Wittmann, F., J. Schongart, and W. Junk. 2011. Phytogeography, species diversity, community structure and dynamics of central Amazonian floodplain forests. In *Amazonian floodplain forests, ecological studies*, ed. W.J. Junk, M.T.F. Piedade, F. Wittmann, J. Schongart, and P. Parolin, 61–102. Dordrecht: Springer.
Wohl, E. 2005. Virtual rivers: Understanding historical human impacts on rivers in the context of restoration. *Ecology and Society* 10 (2): 2. [online] URL: http://www.ecologyandsociety.org/vol10/iss2/art2/.
Wohl, E., P.L. Angermeier, B. Bledsoe, G.M. Kondolf, L. MacDonnell, D.M. Merritt, M.A. Palmer, N.L. Poff, and D. Tarboton. 2005. River restoration. *Water Resources Research* 41: W10301. https://doi.org/10.1029/2005WR003985.
Young, T.P. 2000. Restoration ecology and conservation. *Biological Conservation* 92: 73–83.
Young, T.P., D.A. Petersen, and J.J. Clary. 2005. The ecology of restoration: Historical links, emerging issues and unexplored realms. *Ecology Letters* 8 (6): 662–673.
Zelnik, I., and A. Carni. 2008. Distribution of plant communities, ecological strategy types and diversity along a moisture gradient. *Community Ecology* 9: 1–9.

Chapter 9
Methodologies for the Assessment of River Ecosystem in Southern West Bengal, India

Abstract Southern eco-regions of the state West Bengal (**Lat. 22.0°–23.3° N; Long. 86.0°–88.3°E**), India, is a mosaic of different landscape types, endowed with undulating lateritic terrain with macro and micro gullies. The rate of infiltration is very high on the lateritic upland with dense vegetation cover. However, the upland surface composed of lateritic hard crust with jointed structures and granular materials is endowed with only sparse vegetation because of massive deforestation. Occasionally, the seepage waters from the vegetated uplands can generate a stream flow along the valley fill surface. Four major different aspects of riverine environment are required to be studied in order to gain a complete and holistic knowledge of the ecodynamics of river ecosystem in any area like Southern West Bengal, India.

These studies include long-term recording of physicochemical properties in respect of ongoing threats on river, existing status of biodiversity, and trophic interactions with an eye to compare the present research information with the past in order to understand the trend of ecological changes. Besides, all-round geomorphological and hydro-geological assessment processes have been given due importance for the dynamics and potentiality of riverine flows highlighting their connectivities to the ecosystems in order to devise conservation strategies giving due importance to people's participation. In order to achieve these goals, well-designed eco-monitoring of rivers of different parts of the world have to be conducted to generate baseline information which are to be subjected to existing statistical tools for achieving quantitative definite results. These results pertaining to the status of river environment are to be scientifically processed to arrive at proper decision so that the deteriorating trend of riverine environment may be arrested, restored, and environmentally managed in a sustainable manner and the benefits out of ecological services from the river may be utilized by the local peoples.

Keywords Taxonomic hierarchy · Evolutionary process leading to origin of new species · Traditional vs modern mode of classification · Analysis of different biotic indices · Methods of estimation of different ecological variables · Methods for biomonitoring · Determination of conservation categories of species · Pumping methods for water extraction · Conservation strategies: peoples participation

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9.1 Methodology to Study Varied Forms of Aquatic Fauna with Their Ecology

An array of interactions of different aquatic microbes, plants, and animals with the environment control water quality alongside performing ecological "services," such as production of biomass, decomposition, and nutrient cycling. Identifying species based on their functional roles in aquatic food webs constitutes an essential part of managing biotic communities, especially for undertaking ventures for aquaculture and fishery development. The research information through various ecological assessment procedures on the occurrence, distribution, and overall diversity of organisms starting from bacteria and protozoa to different macrophytes; microphytes; benthic, periphytonic, and planktonic invertebrates; and fishes have established the bioindicator potentialities of those biotic components pointing out the trends of eco-biological changes of the studied fluvial system. Such assessment also depends on the proper identification and recording of pollution-sensitive and pollution-tolerant taxa in order to determine bioindicator species and relevant biomonitoring tools using species diversity as an indicator of pollution with an aim at evaluating the acceptability of riverine water for the human use.

Identification of some species of algae and macrophytes and even faunal components possessing toxic substances is required for maintaining safe water quality. Taxonomic knowhow is also required for spotting and recording of bioinvasion in order to understand the influence of pest and invasive organisms. Finally, different conservation strategies are standardized for the protection of different threatened species alongside their habitats which are supposed to throw more light to shape the decisions for eco-management (**Tables 8.3 to 8.20; Figs. 8.1 to 8.6**).

9.1.1 The Taxonomic Hierarchies with Special Emphasis on Evolution of Species: Foundation of Biodiversity Studies

9.1.1.1 Taxonomic Hierarchy with Special Reference to Species Concept

The science of taxonomy is in a state of perpetual evolution. The initial idea of the taxonomic hierarchy was based on the conviction of descending orders in the classificatory scheme where the splitting of large groups into smaller ones (classes into subclasses) was made. Later, the proposition of taxonomy was moved to an ascending classification system where the related taxa are grouped into taxa of a higher order. The need of classification is twofold: **first,** to identify the organisms based on similarities and dissimilarities among themselves and, **second,** to group the related organisms to place them in proper hierarchy which reflect their evolutionary relationship. Classification of biological organisms deals with the identification and defining of different biological groups or taxa by assigning one scientific name to those organisms possessing at least one characteristic in common. A hierarchical, classification includes smaller groups within larger groups that do not overlap in living world, and each level of the hierarchy corresponds to the name of a taxon. Both these exercises, taxonomy and classification, play important roles for the understanding of biodiversity as being the living structural components in an ecosystem. The phylogenetic hierarchy is based on the evolutionary relationships of groups descending from common ancestors. The principle of classification in the evolutionary perspective upholds that two species are originated from an ancestral species in the process of evolution. Derivation of a group of species from a single common ancestor is designated as monophyletic taxa in contrast to the polyphyletic ones which comprise of those species resembling with one another in many respects but without experiencing direct descendence from a common ancestor.

Biologists consider the species as the fundamental unit of taxonomic division, and the scientific system for naming organisms is based on distinguishing species. An acceptable definition of biological species is "**a genetically distinctive group of populations constituted by the individuals having the power of free interbreeding in the natural ecological conditions after being reproductively isolated from all other members of such groups**" (McFadden and Keeton 1995). Species being the basic unit are grouped together into genera, genera into families, families into orders, and so on. These categories after having their evolutionary origin along rather different lines are roughly comparable from one group to the next. The family represents a coherent group formed by the assemblages of recognizable related genera. Similarly, the order is group of distantly related families. The class represents the major group accommodating varied forms of organisms belonging to different families and differs from other such classes in respect of both structure and way of life. The phyla differ among themselves more vividly and widely in terms of their organization and appearance.

However, many aquatic animals, plants, and microbes are unable for sexual reproduction, while members of many other species can reproduce with organisms that belong to different species as evident from the ability of some fishes to hybridize. The operational definition of species emphasizes the older and traditional concept of species by defining it as **"a group of organisms having close resemblance to other, with respect to their physical appearance by possessing almost similar morphology, physiology, behavior, and reproductive patterns"** (McFadden and Keeton 1995). Sometimes, difficulty arises when individuals of the same species display natural morphological diversity especially those living in different environments. Therefore, in order to undertake appropriate identification efforts, analyzing of such morphological variabilities of a large number of individuals inhabiting in different environmental conditions are required.

Generally, systematists are specialized for a specific group of organisms which highlights the characteristics required for differentiating one species from others. Species are considered as distinct only after the consensus among the majority of systematists studying the group of organisms regarding the distinctiveness of the species. The taxonomic identity based on the current scheme of identification provides a solid foundation for ecological information of a species, especially with the help of electronic search engines which tend to increase such abilities. Besides, the most important taxonomic methods recently use biological molecules, such as **DNA,**

RNA, lipids, and proteins, to ascertain proper status of a species (Graham and Wilcox 2000).

Recently, a very common approach of classifying microbial organisms to its distinct species level requires more than **30%** variabilities of **DNA** sequences or more than **5%** variation of ribosomal **rRNA** sequences (Buckley 2004). But all these methods do not highlight the theory of microbial evolution which advocates the roles of genome as to a coherent group of genes over evolutionary time at some arbitrary degree of **rRNA** similarity.

9.1.1.2 Evolutionary Process Behind the Origin of New Species

Evolution dealing with changes and relationships results in the creation of new species **which** is originated after the splitting of the existing population. The living world not being a static one gives rise to newer creation (species) with the vanishing of others. The possibilities for divergence and evolution are supposed to be higher and rapid in those animal populations where large numbers of offsprings with comparatively smaller-sized individuals are produced in comparison to those which produce fewer numbers and comparatively large-sized individuals having long span of life. The small populations, after being isolated geographically or ecologically, and the genetic variation coupled with selection play more effective roles in bringing about speciation in small community. Therefore, some groups show more species than others. For example, any insect population is having more individuals than a population of birds. The evolutionary processes responsible for the division, divergence, and evolution are the migration, habitat fragmentation, isolation, mutation, genetic drifts, and natural selection. Although animals with more fecundity coupled with shorter longivity have more possibility for evolution than animals with less fecundity and greater longevity, evolution must take longer, and environmental changes must be slower for such animals to the later category of animals to adapt themselves more efficiently. Evolution of species occurs continually and gradually by the agglomeration of so many small changes mainly orchestrated by the genetic shufflings and subsequent filtering by the natural processes. More specialized animals such as many of the mammals are capable of reaching to dominant positions in various habitats within certain period of time but are unable to face the radical changes causing their large-scale mortality.

9.1.2 Traditional vs Modern Mode of Classification

Traditional taxonomic schemes have distinguished among organisms using behavior, metabolic characteristics, and morphology. Traditional taxonomic classifications at the broadest level (kingdom and phylum) are probably not completely natural, and more research is necessary to untangle these evolutionary relationships. Modern approach in turn does not rely mainly on morphotaxonomical characteristics, but instead dependent on molecular, biochemical, and ecological methods.

9.1.2.1 Molecular Assessment Methods for Microbial Diversity in Natural Environments

Microbial ecologists have developed a variety of techniques to identify and determine the taxonomic and ecological status of species that are present in the natural environment along with the assessment of their rates of gene expression. Gene sequences for a tiny subunit of ribosomal **RNA (SSU rRNA, 16S rRNA)** can be extracted from very small samples. Ribosomes, an important cell organelle, function to synthesize proteins and the genetic code for ribosomal structure remains constant and very similar across the whole tree of life an representing **"highly conserved"** properties.

The desired fractions of ribosomal sequence (common with all microbial species) are being used as the **"primer"** of a polymerase chain reaction (**PCR**) for exponentially multiplying the number of replica of the identified **rRNA** genes, which are subsequently sequenced with standard methods. The **PCR** reaction is initiated with the breaking (denaturing) of **DNA** strands into two after increasing the ambient temperature followed by resynthesizing the complementary strands from each half of the two stranded molecules. Repetition of such breaking and synthesis considerably multiplies the newly formed copies of **DNA** from a very small sample. However, some demerits of this method lie with the possibility of biasness in taxonomic identification, the possibility of contamination, and the non-availability of most acceptable primers having universal acceptability for the complementation of the respective sequences common to all organisms (Forney et al. 2004).

After the success of exact amplification of pool **16S rRNA** "identity" genes from a mixed environmental sample, **DNA** fingerprinting techniques were discovered and applied for the appropriate monitoring and assessment of diversity. This molecular technique involves the amplification of subunit **rRNA** genes with **PCR** from a complex community, instead of separating them with regard to their sequence composition, thereby creating a "**fingerprint**" of the taxonomic characteristics of the sample. The desired goals of this method are achieved with the application of denaturing gradient gel electrophoresis (**DGGE**) or terminal restriction fragment length polymorphism (**T-RFLP**). The **DGGE** depends on a gel which possesses a chemical gradient that triggers the increased denaturation of the molecules in the process of their migration through the charged gel. A diversity of molecular and biochemical entities can be ascertained because of their of migration to different distances through the gel.

On staining the resulting bands of **DNA**, a ladder-like configuration of **DNA** helix is revealed that reflects diversity of the genomes. Terminal restriction fragment length polymorphism uses restriction enzymes, enzymes that cut **DNA** helix at specific sequences, in order to produce several smaller **DNA** fragments that are liable to be separated by gel electrophoresis. Owing to the prevalence of phylogenetic variations, **DNA** fragments exhibit different lengths in **DNA** sequences.

Analyzing of restriction polymorphism with a gel also result a pattern of bands, commonly designated as a "**fingerprint**," decoding of which enables to develop understanding on taxonomic composition of organisms, especially on diverse microbial communities. It also appears to be possible for separating the functional genes by combined application of targeted **PCR** of environmental genes and fingerprinting techniques. These methods applicable to eukaryotic species hold great promise in the pinpointed determination taxonomic identity of species.

9.1.3 Major Taxonomic Groups: Based on Molecular to Macro-anatomical Features

Three major groups of organisms have been proposed at the broadest level of classification: the Eukarya (eukaryotes), the Bacteria, and the Archaea (Woese et al. 1990). The Bacteria and Archaea were known formerly as the Prokaryota. Prior to the discovery of microscopic and chemical assessment techniques, unique cellular composition of bacteria could not be recognized, and during that period, organisms were classified only as animals (mobile) or plants (sedentary and green). After the establishment of light microscopy, the classification dividing organisms into animal and plant groups became difficult because many microbes were found to exhibit photosynthetic, motile, and sometimes simple behaviors (attraction to light or food).

The observation of those diverse microbial lifestyles obscured conventional distinctiveness between animals and plants. Invention of electron microscopy allowed definitive differentiation between organisms with complex inner architecture (eukaryotes) and those with more simple cells (then called prokaryotes). Recently, analysis of **rRNA** and other biological molecules has revealed that the Archaea originated from the Eukarya shortly (relative to the **4**-billion-year-old Earth) on their divergence from the Bacteria. Such analyses have also recommended the assignment of the status of super kingdoms instead of the traditional kingdoms for the Archaea, Bacteria, and Eukarya (Woese et al. 1990).

9.1.4 Classification Based on Nutritional Abilities

In the domain of aquatic ecology, taxonomy of organisms is based not only on phylogenetic relationships but also on their functional roles in communities and ecosystems. Organisms can be autotrophic (**self-feeding**) relying on carbon dioxide (**CO_2**) as the primary source of carbon to build cells in contrast to those of other heterotrophic organisms feeding on other organisms (predation, herbivory, parasitism, etc.) to acquire carbon (dissolved or particulate organic compounds or dead organisms) for cells from organic carbon. Some organisms also use both autotrophic and heterotrophic processes to obtain carbon. Heterotrophs that decompose organic carbon are sometimes called saprophytes or detritivores.

9.1.5 Classification of Organisms Based on Function Roles

A variety of additional classifications are used to describe the functional roles of organisms in aquatic food webs which are designated as functional feeding groups (Cummins 1973). Organisms that sieve particles from the water column are called filterers. Organisms that build nets or have morphological features that filter particles out of flowing waters are passive filterers, whereas those that actively pump water or create currents are active filterers. Aquatic organisms, mostly benthic fauna that acquire their nutrition from small organic particles, are called collectors. Shredders break up larger organic materials like decaying leaves for their nutrition, and scrapers remove biofilms from hard benthic substrata.

Functional feeding groups are somewhat similar to guilds, the concept based on which highlights organisms using the same resource in the same fashion (Root 1967). Members of the same functional group may use different resources. For example, some shredders may feed on decomposing leaves, whereas other shredders may feed on decomposing or living aquatic plants, but they all shred large organic materials. Functional and guild analyses can be more relevant than taxonomic considerations for relating organisms to ecosystem processes like nutrient cycling and energy flow. Consumers are often classified further by their position in the food web. For example, grazers or herbivores (primary consumers) eat algae, plants, or sometimes bacteria (primary producers). Carnivores or secondary consumers eat other animals, and top carnivores eat animals but are generally eaten by no larger animal. Thus, classification schemes based on modes of obtaining nutrition are one of the many ways to classify organisms.

9.1.6 Classification of Aquatic Organisms Based on Their Habitats

Additionally, organisms may be classified by the habitat they occupy (**Table 8.1**). Such classification can become useful as it allows an investigator to make predictions about abiotic and biotic conditions important to organisms. Aquatic organisms are broadly classified into two categories – first one exclusively live in water throughout their life span, and others require both water and sediments for their survival. The true aquatic one is known as pelagic while the latter one as benthic organisms.

The pelagic organisms are further classified as plankton (floating organisms) that requires the help of water movement for their own change of position and nekton that represents the free-floating animals (fish). Planktons are further classified as zooplankton (animals) and phytoplankton (plants) based on their ability to undertake nutrition. The benthic fauna in accordance with their sizes are distinguished as macrobenthos, meiobenthos, and microbenthos.

Macrophytes are large plants residing both in the water column and water–soil interphase of aquatic ecosystem. Microphytes are always in need of water, representing mostly the microscopic plants. Besides, another important category of organisms is present mostly in freshwater system, termed as periphyton, where organisms, both plants and animals, present remain attached with the hard structures within the water bodies.

9.1.7 Classification of Organisms Based on Species Interactions

Based on the types of interactions among themselves (interspecific interactions), organisms can also be classified into different categories in tune with different types of interaction schemes such as direct and indirect interactions (**Table 8.2**). Direct interactions occur between individuals of two species and involve no other; indirect interactions are mediated by other species. Exploitation is a general term for an interaction that harms one species and helps another. This term is not widely accepted yet, but includes interactions that may not be formally considered predation or parasitism. For example, an epiphyte that harms a macrophyte but receives benefit from living on its leaves is exploiting the plant. Mutualism is used to denote any positive reciprocal interaction. Others have used various terms to denote mutualism, including symbiosis, synergism, and protocooperation. Symbiosis highlights a close relationship instead of the active mode of interactions in between species, whereas synergism and protocooperation have not received widespread use outside of studies of animal behavior. Of all the interaction types found in macroscopic ecological communities, commensalism (positive on one, none on the other) and amensalism (negative on one, but no effect on the other) are likely the most common, followed by exploitation and then competition and mutualism (assuming that positive interactions are as likely as negative interactions (Dodds 1997; Dodds and Nelson, 2006)). In general, commensalism and amensalism have received almost no attention in the ecological literature; predation has received the most, followed by competition and mutualism.

9.1.8 Classification of Organisms Based on the Power of Tolerances of Ecological Parameters

The successful settlement and survival of a species within a community are controlled by a number of ecological factors which operate independently in association with one another, forming complex ecological conditions. Any factor or condition that exceeds the limits of tolerance is designated as limiting factor. Under stable conditions, the essential constituent available in amounts most closely approaching the minimum need to be the limiting one, a concept termed **Liebig's law** of the minimum. This has led to develop the concept of limits of tolerance which highlights and stresses upon the limiting effect of maximum as well as minimum constituents on diversity and distribution of organisms. This has been elaborately explained by the theory, known as **Shelford's law of tolerance** (Shelford 1913). Based on the discussion on **Liebig's law of minimum** and **Shelford's law of tolerance**, a good number of terminologies have surfaced for the general use in the subject ecology that use the prefixes **steno**- meaning "**narrow**" and **eury**- meaning "**wide**" **(Tables 8.1 and 8.2 and Fig. 8.1)** which are as follows:

1) **Steno and eurythermal:** Narrow and wide range of tolerance of temperature
2) **Stenohaline-euryhaline**: Narrow and wide range of tolerance of salinity
3) **Stenoecious-euryecious**: Narrow and wide range of tolerance of habitats

A tolerance model proposed by Connell and Slayter (1977) advocates that a species may invade a new habitat and becomes established within it independently irrespective of the presence or absence of other species. Some traditional and well-established marine species, such as sponges and jellyfish, are often encountered in small numbers from freshwater habitats. Some freshwater invertebrates (aquatic insects, arachnids, etc.) are considered as secondarily aquatic organisms after having evolution from the terrestrial forms which were earlier evolved from the marine ancestors. Secondarily adapted aquatic organisms colonized and adapted to freshwater habitats by possessing specialized morphological or physiological features that reflect their terrestrial ancestry. For example, aquatic insects mostly adapted to terrestrial system for their respiration with spiracles, trachea, etc., breathe in atmospheric air, and spend the bulk of their time underwater with some modifications of their morphoanatominal features to suit for aquatic environment.

9.1.9 Assessment of the Diversity and Assemblages of Freshwater Fauna

Invertebrates representing the most fascinating freshwater organisms by virtue of their abundance, diversity, and adaptive flexibility enjoy a diversified ecological niche and habitats in any freshwater ecosystems (Chakraborty et al. 2005). This group of living organism displays astonishing form of diversity of body forms, life cycles, and behaviors among all other aquatic fauna and flora. Owing to their abundance, diversity, and relatively fast growth rates among individuals and population, invertebrates have become ecologically very sensitive and productive in freshwater habitats, with the regulating effects on other groups of organisms (Wallace and Webster 1996; Thorp and Covich 2001; Dodds et al. 2004).

However, identification up to species level of several rare but interesting taxa along with larval forms of many known invertebrates poses real difficulty because of the lack of proper taxonomic keys. Vertebrates also depict higher abundance and diversity in freshwater habitats, although the major share of such diversity is made for only one group, the bony fishes (superclass Osteichthyes). However, most of the vertebrates those abound primarily in the freshwater environment are fishes, whereas other higher animal groups such as birds and mammals are partially aquatic. Some other vertebrate groups (frogs and salamanders) exhibit biphasic amphibious life cycles; a part of their lives is spent in water and the rest on lands.

Identification of vertebrates has appeared easier than invertebrates because the former are represented by fewer and larger animals, but still identification of species such as small-sized fishes (some minnows and darters) and larval forms of amphibians requires competency and expertise.

9.1.10 Assessment of Floral Assemblages in Freshwater River Ecosystem

Many plants in aquatic systems have been well characterized. Emergent wetland species generally are included in traditional plant taxonomic references (Michael 1968; Smith 1977; Sharma (1983, 1992, 1993, 1998); Pradhan & Chakraborty (2008); Halder Mallick and Chakraborty (2014); Halder et al. (2007); Sharma and Sharma (2010); Sharma et al. (1999); Sharma and Saini, (2016); Sinha (1992); Sladecek (1995); Suther et al. (2009). For more obscure mosses and liverworts, identification is more difficult, and even some larger groups such as sedges can be problematic to identify. Truly aquatic plants are only moderately diverse; and they not only act as an important structural component of the ecosystem but profusely contribute towards ecosystem function (Riemer 1984).

9.2 Analysis of Biotic Community: Types and Analysis

Biodiversity of an ecosystem is being recorded and quantified just by observing and counting taxa and estimating their frequency. These strategies typically distinguish estimating between alpha and beta diversities. The **alpha (α) diversity** was introduced by **R.H. Whittaker** in the year 1972 who referred it as the mean species diversity within the habitats at a local scale or within a particular habitat patch with its local taxon richness (usually species richness) and the number of taxa found in the community, weighted by abundance. A system with one very numerous species and a few rare ones is less alpha diverse than one in which the species are equally abundant. The **beta (β) diversity** is the variation of the species composition between two habitats. It takes into account the alpha diversity of the habitats and the number of unique species on each habitat. Beta diversity (and its relatives) is very important to conservation planning, because that planning typically involves the selection of an ensemble of sites to maximize the overall protection of biodiversity. The **gamma diversity** refers to the overall diversity for different ecosystems within the region, and therefore, it can be projected as the product of both alpha and beta diversities. The difference between one community and others already protected is often as important as the intrinsic richness of a community. The information about species richness on combining the information of abundance makes the way of calculating the Shannon Wiener Diversity Index and Simpson's Index.

9.2.1 Analysis of Different Biotic Indices

9.2.1.1 Deduction of Different Community Indices

Effect of environmental factors was assessed by comparing the community structure of different mollusks from different study sites. A community is a naturally occurring and interacting assemblage of plants and animals inhabiting in the same habitat in order to fix, utilize, and transfer energy to maintain the ecological stability of an ecosystem. Community structure analysis includes the following:

(a) **Relative abundance**: **Relative abundance (RA)** of different species in the community was determined by using the following expressions:

Relative Abundance (RA) = ni/N × 100 where ni = total number of individuals of in the species and N = total number of individuals of all the species. Dominance of species was ascertained on the basis of relative abundance. Species with RA, exceeding **5%**, were regarded as dominants, those between **2.5%** as subdominant, and remaining species as rare.

(b) **The species rank abundance (SRA)**: The species were ranked in order of abundance. The most numerically abundant species is ranked as one (Shaw et al. 1983).

Some additional analysis such as index of dominance (Simpson 1949), index of similarity (Odum 1950; Sorensen 1984) in between the study sites, species richness index or variety index (Menhinick 1964), species diversity index (Shannon and Weaver 1949), and species evenness index (Pielow 1966) are studied by using the following expressions:

(c) **Index of dominance (C) = $((ni/N)^2$ where ni = importance value for each species (number of individual) and N = total of importance value.**

(d) **Species richness or variety index (d) = $S/\sqrt{N}$ Or (d = SI/LnN) where S = number of species and N = total number of all species.**

(e) **Species diversity index (H^{-}) = − (Pi log Pi = − ((ni/N) log (ni/N) where ni = importance value for each species; N = total of importance values; and Pi = importance probability for each species (ni/N).**

According to Wilhm and Dorris (1966), when the value of diversity index exceeds **3** (>3), the quality of water would be clean; when this values ranged from **1** to **3**, the water quality would be moderately polluted; and when it is less than 1 (<**1**), the quality of water would be grossly polluted.

(f) **Evenness index (e) = H¯/log S where H¯ = diversity index and S = number of species.**

(g) **Index of similarity (%S) = where A = number of species in one study site; B = number of species in another study site; and C = number of species common to both study sites.**

9.2.2 Cluster Analysis: A Statistical Tool to Visualize the Relationship

Single-linkage clustering technique is the simplest form of hierarchical and agglomerative cluster analysis. This analysis is based on a matrix of similarity coefficients (Krebs 1999). The method is initiated to identify most similar pairs of samples, which are considered as the first cluster, and thereafter to determine the second most similar pair of samples or cluster having the highest similarity between a sample and the first cluster, whichever is greater. The cycle has to be repeated in steps until the samples reach to one big cluster.

9.2.3 MANOVA: Modified Form of ANOVA – Duncan Test

Multivariate analysis of variance (MANOVA) at **5%** level of significance is used to test the seasonal variation in overall species composition of biotic community, whereas analysis of variance (**ANOVA**) is computed to test for significant difference (P < **0.05**) of environmental parameters.

Duncan's post hoc tests are employed to check the differences in the abundance of individual species and physicochemical parameters among the seasons. **Analysis of similarities (ANOSIM)** is performed to find out the existing significant differences among the constituent species in a biotic community in different seasons. Similarity percentage analysis (**SIMPER**) is usually made to observe the percentage of similarity and percentage of major contributing species among seasons.

Nonmetric multidimensional scaling (nMDS) is done to allocate the similarity among the seasons in terms of species abundance with log**10** (1 + x) transformed data. For the assessment of the environment influence on biotic community structure, the Biota and Environmental Matching Routine (**BIOENV**) package is used to determine the best match between multivariate constituent species abundance pattern and ecological parameters such as temperature, **pH**, dissolved oxygen, salinity, alkalinity, etc. All ecological parameters are to be subjected square-root transformation and standardization before analysis. The best matches of biological and environmental parameters are measured using the **Spearman rank correlation**

coefficient. **Canonical correspondence analysis (CCA)** is calculated to find out the association between species and physicochemical parameters using the software **PAST** 3 (Paleontological Statistics).

9.2.4 Estimation of Different Heavy Metal Indices

9.2.4.1 Determination of Contamination Factor (CF)

Contamination factor (CF) for each metal was determined as

$$\mathbf{CF = Observed\ metal\ concentration\ (Cn)/Background\ concentration\ of\ the\ same\ metal\ (Bn)}.$$

9.2.4.2 Deduction of Pollution Load Index (PLI)

Pollution load index for each site for ecological study is calculated by the method and equation proposed by Tomlinson et al. (1980):

$$\mathbf{PLI} = \sqrt[n]{(\boldsymbol{CF1} \times \boldsymbol{CF2} \times \ldots\ldots.. \times \boldsymbol{CFn})}$$

where **CF** refers to the contamination factor and n is the number of parameters.

9.2.4.3 Calculation of Geoaccumulation Index (I_{geo})

The value of **geoaccumulation index (I_{geo})** for each metal is determined following Muller (1979):

$$I_{geo} = \log_2 C_n / 1.5 \times B_n$$

where **Cn** is the observed concentration of metal in the sediment, **Bn** is the geochemical background concentration of that metal, and **1.5** is the correction factor for the background matrix due to lithogenic effect.

9.3 Biotic Indices and Their Applicability in the Assessment of Ecological Changes

A biotic index takes account the sensitivity of tolerance of individual species or groups to pollution and assigns them a value, the sum of which gives an index of pollution for a site (Gfetil and Ravera 1994; Karr (1981); Karr (1991); Karr (1999);

Sharma, 2001; Pradhan and Chakraborty, 2008; Lange and Lange, 1997; Kwok et al. 2007). The data may be qualitative (presence–absence) or quantitative (relative abundance or absolute density). These indices are deducted mainly to evaluate the organic pollution caused by organic pollutants. The saprobien system devised by Kolkwitz, 1935; Kolkwitz and Marsson, 1902 and Kolkwitz and Marsson (1908) is the earliest biotic index.

Polysaprobic, a-mesosaprobic, ß-mesosaprobic, and oligosaprobic zones from the higher organic enrichment to decreasing state in river are demarcated based on the intensity of pollutants and also by virtue of the trend of occurrences (the presence or absence) of indicator species in the said zones. Pantle and Buck (1995) also had developed the saprobien system by emphasizing the relative abundance of organisms in a biotic community.

9.3.1 *The Saprobic Index of Pantle and Buck*

Saprobien groups		Relative abundance	
	S value		h value
Oligosaprobic	1	Occurring accidentally	1
β-mesosaprobic	2	Occurring frequently	3
α-mesosaprobic	3	Occurring abundantly	5
Polysaprobic	4		

$$\text{Mean saprobic index (S)} = \text{sh}/\text{h}$$

1.0–1.5	Oligosaprobic	No pollution
1.5–2.5	β-mesosaprobic	Weak organic pollution
2.5–3.5	α-mesosaprobic	Strong organic pollution
3.5–4.0	Polysaprobic	Very strong organic pollution

In grossly polluted waters, where no macro-invertebrates are present, a **TBI** of zero is obtained. The maximum score in unpolluted water with a species-rich invertebrate fauna is **0**.

9.3.2 *Chandler Biotic Score (CBS)*

According to Chandler Biotic Score (1970), the abundance of organisms within the community, as well as the species richness, is of value in assessing the degree of pollution. This index has five levels of abundance, the score of each indicator species being weighted in relation to its abundance.

If a species, intolerant of pollution, is abundant, it is given a high score (**100**), whereas an abundant, pollution-tolerant species is given a low score (**4**). The allocation of scores is somewhat arbitrary. The lower limit of the score is zero, in which no macro-invertebrates are present, while there is no upper limit.

Comparison of physicochemical monitoring with biological monitoring

S. no:	Characteristics	Physicochemical monitoring	Biological monitoring
1	Pollutant concentration	Good	Poor
2	Assessment of intermittent, irregular pollution discharge	Not possible unless continuously monitored	Possible without continuous monitoring
3	Kind of pollution assessment	Good	Poor
4	Reliability (representation of data)	Poor	Good
5	Measure of ecological effect	Not possible	Possible
6	Monitoring	Relatively high	Relatively low

9.3.3 Advantages of Biological Assessment

1. The biological methods are quite quick and economical and can be integrated with other relevant studies.
2. Much less equipment are required, and large area can be surveyed in less time resulting in large amount of information suitable for assessment.
3. Provide cheaper option in comparison to physicochemical assessment, where chemical analytical equipment, manpower, and operation costs are very high. Biological assessment methods do not eliminate the need for chemical analysis of water samples; however, these may provide information, which may be integrated with physicochemical information. The integration of biological method with physicochemical method may provide a system, which is not too expensive, and generate necessary information with maximum efficiency.

9.3.4 Ecological Information Generated by Biological Assessment

Biological assessment relies on the fact that pollution of water body will cause changes in physicochemical environment of water and that those changes will disrupt the ecological balance of the system. The measure of extent of ecological upset will depict the severity of pollution. The biological systems used as water quality indicators should have the following characteristics:

1) The presence or absence of organisms acts as a function to denote water quality than any other ecological factors.
2) The biological system can be reliably used to assess the trend of changes of water quality, which are expressible in simplified form instead of sufficiently quantifiable level to undertake comparison with other such information.
3) Bio-assessment water quality should be conducted an extended period rather than at the time of sampling alone.
4) Bio-assessment focuses on the point of sampling rather than other watercourse as a whole.

9.3.5 Parametric and Nonparametric: Demystifying the Terms

Parametric and nonparametric represent two broad classifications of statistical procedures.

The most comprehensive, brief, and simple but universally acceptable definition of the term "**nonparametric**" is still wanting. It holds some general assumptions that are satisfied to a reasonable approximation. Parametric tests also rely on assumptions pertaining to the distribution of the underlying population from where the sample was taken.

The most common parametric assumption is that data are approximately normal. Nonparametric statistical procedures do not rely on the assumptions about the structural factors of the representative samples of the population. Although nonparametric tests depend on very few assumptions about the distribution of measurements in the population from which one can draw sample, this procedure suffers from two demerits. The first are with less rankings of the values in the data rather than using the actual data.

9.4 Analysis of Physicochemical Parameters of River Water

9.4.1 Physical Parameters

(i) **Temperature**: Distinct temperature layers exist in aquatic habitats. The metabolic rate of aquatic life increases at higher temperature, leading to the enhancement of dissolved oxygen (Saha et al. 2001). Temperature of the water sample was measured by mercury thermometer having **0.1**°C graduation.
(ii) **pH**: **pH** is defined as the negative of the logarithm to base 10 of the hydrogen concentration. Odum (1971) reported that water with low pH was found deficient in nutrients. pH of the water was calculated using Griph pH meter that was calibrated with pH buffer **4.0** and **7.0** before use. It consisted of glass membrane electrode.

The clean electrode was immersed into **100** ml beaker full of water sample. The solution was stirred, and the reading is taken after stabilization for about 2 minutes.

(iii) **Transparency:** Transparency is an expression of optical property. This was determined using **Secchi disc method**. It consists of a circular iron plate having **20** cm diameter with the surface painted with alternate black and white (Michael 1984).

Secchi disc transparency is expressed in centimeters. Initially the disc has been dipped slowly into the water until it just disappears. This depth was measured by noting the length of the rope (**L1**). Then the disc is lowered further down and slowly raises it until it reappears. This depth was measured (**L2**). Final disc depth was measured from the average of these two readings. This procedure was repeated thrice.

Transparency was measured using the following expression:

Secchi disc transparency (cm) = A + B/2

where **"A"** is depth in cm where **Secchi disc** disappears and **"B"** is depth in cm where Secchi disc reappears.

(iv) **Carbonate alkalinity**: The capacity of water to neutralize a strong acid is known as alkalinity.

(v) **Total alkalinity**: It is estimated by titrating the water sample with strong acid (**HCl**) using phenolphthalein indicator at high **pH** (**7** to **8**) and using methyl orange indicator at low **pH** (**4** to **5**). **100** ml of water sample was taken for each study (APHA 2005). From the titration values, the total alkalinity was calculated using the following equation:

$$\mathbf{TA} \text{ as } \mathbf{CaCO_3}, \ \mathbf{mg/l} = \frac{(\text{ml} \times \text{Normality}) \text{ of } \mathbf{HCl} \times 1000 \times 50}{\text{ml of sample}}$$

(vi) **Calcium hardness**: Calcium hardness is determined with **EDTA.**

When the **pH** was adjusted to **12** by addition of 1 (**N**) NaOH, magnesium is precipitated as magnesium hydroxide. The Murexide indicator is used which indicates the end point by showing the sharp color change from pink to purple (APHA 2005; Trivedy and Goel 1984):

$$\text{Free } \mathbf{CO_2}, \ \text{mg/l} = \frac{(\text{ml} \times \text{N}) \text{ of } \mathbf{NaOH} \times 1000 \times 44}{\text{ml sample}}$$

(vii) **Magnesium hardness**: Magnesium hardness is the difference between total hardness and calcium hardness.

Magnesium hardness as $CaCO_3$ (mg/l) = Total hardness as $CaCO_3$ – Calcium hardness as $CaCO_3$

(viii) **Conductivity**: Conductivity is the capacity of the water to conduct electricity. It is an indirect measure of salt concentration, and it depends upon the level of ions and nutritional status. The conductivity of the water sample is measured using "**digital conductivity meter**" (Systronics Type 304) by dipping the conductivity cell in the sample contained in the beaker. At the time of measurement, the temperature of the sample is also noted. Conductivity is expressed in **μ** mho/cm.

The recent unit of conductivity has been named as Siemens **(S)** instead of mho.

(ix) **Total dissolved solid** (**TDS**): The total amount of dissolved chemical species in water is called total dissolved solids. In general, freshwater has less than 1500 mg/l of **TDS** (Trivedy and Goel 1984).

(x) **Total dissolved solids (TDS)** are determined initially as the residue left after the evaporation of the filtered sample. Then the **250** ml water sample is filtered through **GF/C** filter paper and evaporated at **103** °C. **TDS** is measured in **gm/l**:

$$\mathbf{TDS}(\mathrm{gm/l}) = \frac{\mathrm{A-B\times 1000}}{\mathbf{volume\ of\ sample\ taken\ (ml)}}$$

where, **A** = Final weight of the dish in **gm** and **B** = Initial weight of the dish in gm.

(xi) **Total suspended solid** (**TSS**): Total suspended solids are the solids present in a suspended state in water. **TSS** is calculated using the following equation:

$$\mathbf{TSS}\ \text{in}\ \mathbf{mg}/\mathrm{l} = \frac{\mathrm{A-B\times 1000}}{\text{volume of sample}}$$

where, **A** = Final weight of filter paper and **B** = Initial weight of the paper before filtration.

9.4.2 Chemical Parameters

9.4.2.1 Organic Parameters

Dissolved Oxygen

It is measured using Winkler's iodometric method, the procedure of which is first conceived and established in the year **1988** by L.W. Winkler, in Hungary.

In this method, the oxidation of manganous hydroxide (bivalent form of manganese) is oxidized by the dissolved oxygen in the water, leading to the formation of tetravalent compound, the acidification of which liberates free iodine because of the oxidation of potassium iodide. Prior to that, a white precipitation of manganous hydroxide is formed out of the reactions of manganous sulfate with the alkaline iodide solution, which immediately gets oxidized by oxygen to a brown color compound.

The amount of free iodine, chemically equivalent to the amount of dissolved oxygen, is determined by titration with a standard solution of sodium thiosulfate (**0.005** M) using starch as an indicator. The water sample is filled in a **100** ml glass stoppered bottle avoiding any kind of bubbling. Then **1** ml of each $\mathbf{MnSO_4}$ and alkaline **KI** solution is added to it. The solution is shaking well. Then **2** ml of concentrated $\mathbf{H_2\ SO_4}$ is added to dissolve the precipitate.

50 ml of the solution is taken for titration. It is titrated against sodium thiosulfate solution using starch as an indicator. At the end point, initial dark blue color changes to colorless. Chemical reactions are as follows:

$$\mathbf{MnSO_4 + 2KOH = Mn\ (OH_2) + K_2SO_4; Mn(OH)_2 + O_2 = 2MnO(OH)_2}$$

$$\mathbf{2MnO(OH)_2 + 4H_22SO_4 = 2Mn(SO_4) + 6H_2O}$$

The number of moles of iodine liberated by this reaction is equivalent to the numbers of moles of oxygen present in the sample. The quantity of iodine is determined by titrating a portion of the solution with a standard solution of sodium thiosulfate:

$$\mathbf{2MnO\ (SO_4) + 4KI = 2MNSO_4 + 2K_22SO_4 + 2I_2}$$

$$\mathbf{4Na_2\ S_2O_3 + 2I_2 = 2Na_2S_4O_6 + 4NaI}$$

$$\text{Dissloved Oxygen (in mg/l)} = \frac{\textbf{Volumer of } \mathbf{Na_2S_2O_3} \textbf{ used for titration (in ml)} \times \mathbf{N(Na_2S_2O_3) \times 8 \times 1000}}{\textbf{Volume of sample taken for titration (in ml)}}$$

where N = **Normality of thisosulfate**
8 = **Equivalent wt of oxygen**.

Chemical Oxygen Demand (COD)
COD of the water sample is determined using titrimetric method. **20** ml of water sample is taken in a **250** ml of **COD** flask. **10** ml of **0.025** N potassium dichromate solutions is added.

A pinch of $\mathbf{Ag_2SO_4}$ and $\mathbf{HgSO_4}$ is also added which was followed by **30** ml of $\mathbf{H_2SO_4}$. Then the solution was refluxed for **2** h. The solution is cooled. Finally, it is titrated with **0.1** N ferrous ammonium sulfate in presence of Ferroin indicator (Trivedy and Goel 1984). The blank test is performed. It is measured using the following equation:

$$\mathbf{COD, mg/l} = \frac{(\boldsymbol{b - a}) \times \mathbf{N\ of\ K_2Cr_2O_7 \times 1000 \times 8}}{\mathbf{sample\ volume\ (ml)}}$$

where **a** = ml of titrant with sample
b = ml of titrant with blank.

Biochemical Oxygen Demand (BOD)
Biochemical oxygen demand (**BOD**) is estimated as mentioned in following method:

In this method, three oxygen bottles were filled with water to be analyzed. All three bottles were numbered. To the first bottle, Winkler's reagent is added immediately on collection. Two other bottles are stopped without trapping any air bubbles. These untreated bottles are placed in the dark in an incubator at **20** °C and incubated for **5** days. It is calculated by measuring the difference of the dissolved oxygen concentration between the sample and after incubating it for **5** days at **20** °C.

9.4.2.2 Inorganic Parameters

Total Kjeldahl Nitrogen

It is estimated by digestion and distillation method (Trivedy and Goel 1984). **40** ml of water sample is taken in Kjeldahl flask for digestion. **4** ml of conc. $\mathbf{H_2SO_4}$, **10** drops of $\mathbf{CuSO_4}$, **6** gm of solid $\mathbf{K_2SO_4}$, and **1** ml of **10% NaCl** solution were added in it. The solution was diluted to some extent. Then the distillation is performed. Finally titration is carried out using the distillate with 0.01 NHCl until the color changes from blue to faint pink. This is estimated using the following equation:

$$\text{Kjeldahl Nitraogen (mg/l)} = \frac{(a-b)\times\mathbf{0.01}\times\mathbf{1000}\times\mathbf{14}\times\mathbf{d}}{\textbf{volume of sample distrilled}}$$

where **a** = Volume of **HCl** used with sample
b = Volume of **HCl** used with blank
d = dilution factor.

Phosphate Content

Phosphate is an essential element for the entire living organism.

Total phosphate content in water sample was measured spectrophotometrically (Systronics-**20**). The sample was digested in the presence of **4** ml $\mathbf{H_2SO_4}$, **10** drops $\mathbf{CuSO_4}$ solution, and **6** gm of solid potassium sulfate. The solution was diluted and 1 drop of phenolphthalein was added to it. It was neutralized by titrating with 5 N **NaOH**. At the end point, the solutions turn pink, which disappears after addition of ammonium molybdate. The concentration of phosphorous was determined from the standard curve (Trivedy and Goel 1984).

Chloride Content

Chloride content of the water is an important pollution index.

Higher values of chloride may be attributed because of decomposition of organic matter, whereas the minimum values are due to consumption of ions by the macrophytes (Trivedy and Goel 1984). It was done by titrimetric method involving direct titration of the solution with $\mathbf{AgNO_3}$ (**0.02** N) using $\mathbf{K_2CrO_4}$ as an indicator. The chloride content was calculated using the following equation:

$$\text{Chloride (mg/1)} = \frac{(\textbf{Volume}\times\textbf{Noemality})\ \textbf{of}\ \mathbf{AgNO_3}\ \textbf{required}\times\mathbf{35.5}\times\mathbf{1000}}{\textbf{volume solution taken (ml)}}$$

Salinity

Salinity of the water is determined using the following empirical equation:

$$\textbf{Salinity (g/l)} = \mathbf{0.03} + \mathbf{1.805} \times \textbf{Chlorides (mg/l)}\ \text{(Trivedy and Goel 1984)}$$

9.4.2.3 Microbial Parameters

Coliform (Total and Fecal)

The most probable number of coliforms in a water sample can be estimated using the multiple tube fermentation techniques (Trivedy and Goel 1984). This technique involves inoculating the water sample at several dilutions in a suitable liquid medium. All are placed in an incubator at **35 °C** for **30 min** for at least **48 h**. After the incubation period, they are examined for gas production by coliform organisms. The density of bacteria is calculated on the basis of positive and negative combination of tube using **MPN tables**. Total coliform value is expressed in the form of **MPN/100 ml**. Since the coliforms in water may be derived from the sources other than the fecal, so the separate test for fecal coliform has to be performed. They are supposed to inoculate in lactose and incubate for **24 h** at **44 °C**. Finally the confirmatory test is performed:

$$\mathbf{MPN/100\ \ ml} = \frac{\mathbf{MPN\ \ table\ \ value \times 10}}{\mathbf{starting\ \ dilution}}$$

9.5 Analysis of Bottom Soil Parameters

9.5.1 Soil Temperature (°C)

Using soil thermometer.

9.5.2 pH

pH of soil was determined with the help of a glass electrode digital **pH** meter (**EC**, **pH 5652**) using a **soil/water ratio** of **1:2.5** as proposed by Jackson (1973).

9.5.3 Salinity (o/oo)

The salinity of a soil suspension was determined using Knudson's method (Strickland and Persons 1968).

9.5.4 Organic Carbon o/o

Organic matter of the soil was determined by Walkley and Black's (1934) rapid titration method. The organic matter of the soil was digested with excess of

$\mathbf{K_2Cr_2O_7}$ and $\mathbf{H_2SO_4}$. The residual unutilized matter ($\mathbf{K_2Cr_2O_7}$) was then titrated against ferrous ammonium sulfate.

Calculation was made using the formula:

$$\mathbf{o/o\ \ Organic\ \ Carbon} = \frac{\mathbf{3.951}}{\boldsymbol{gm}}(\mathbf{1 - T/S})$$

where

gm = wt. of sample.
S = ml of ferrous solution with blank titration
T = ml of ferrous solution with sample solution

9.5.5 Soil Texture (°/o)

Textural composition of soils was estimated by means of mechanical analysis following standard methods (Black 1965; Jackson 1967; Strickland and Parsons 1968). For textural analysis, **20 gm** of shade dried sample was first digested with **6%** $\mathbf{H_2O_2}$, till the sample was free of organic matter.

The soil was then treated with dilute **HCl** to remove the free calcium carbonate and washed and shaken thoroughly with **NaOH** to bring complete dispersion. The suspension was transferred to a **1000 ml** cylinder. After **4** min, **20 ml** of sample was pipetted out from **10 cm depth** and dried to constant weight to obtain the weight of silt and clay (**X gms.**).

The pipetting was repeated in similar manner after **6 h** to get the weight of clay alone (**Y gms.**).

$$\mathbf{Chloride\ \ (mg/l)} = \frac{\mathbf{(Volume \times Normality)\ \ of\ \ AgNO_3\ \ required \times 35.5 \times 1000}}{\mathbf{volume\ \ of\ \ solution\ \ taken\ \ (ml)}}$$

Percentage of sand, silt, and clay in the soil was determined by using the following calculation:

$$\mathbf{\%\ \ of\ \ clay = Y \times 250}$$
$$\mathbf{\%\ \ of\ \ slit = (X - Y) \times 250}$$
$$\mathbf{\%\ \ of\ \ sand = 100 - (X \times 250)}$$

9.6 Eco-monitoring and Biomonitoring a Tool for Eco-assessment of Ecosystem Health

In view of the ongoing perturbations and eco-degradations in most of the ecosystems of the world, the ecosystem health is being assessed in respect of the community structure (species richness, species composition, food chains and food webs, trophic interactions, etc.) and ecosystem functioning (productivity, energy flows, nutrients cycling, etc.). Eco-management strategies are designed and executed giving due importance to the existing human perceptions and actions, state of community structure, and ecosystem functioning and management response (Fairweather 1999). Identification and application of some ecological indicators have been found to contribute better diagnosis of the environmental problems so that effective steps can be taken to combat the deteriorating ecosystem health (Stark 1993; Chakraborty et al. 2005; Maity et al. 2013; Chakraborty et al. 2021).

The concept of ecosystem health of rivers, after being enunciated as a social construct, can be evaluated in a number of ways, starting from the assessment of abiotic interactions and resultant processes (nutrient budgeting and sedimentation processes), ecodynamics of species interactions and flows of matters and energy, and proper realization of societal expectations and involvement. A healthy ecosystem is one that the community believes to be healthy, and different social groups hold different views and ideas about this (an angler is satisfied on getting preferred fish species, peoples regularly taking baths are happy if they do not develop any diseases, etc.) (Begon et al. 2006).

Environmental monitoring is meant for programed process of measurement and collection of information about the existing status of environment and can be done by physicochemical and biological methods. Physicochemical monitoring deals with quantitative estimation of physical and chemical parameters of environment. On the other hand, employing of biological parameters for assessing environmental perturbation is termed as biomonitoring. The appropriate monitoring systems are required to recognize and predict the ecological changes caused by human-mediated hazardous activities. As life is the best indicator of environment, several biomonitoring methods have been devised using biological criteria for successfully predicting the impact of several human activities, especially the human-contributed pollutants, well in advance since they present effective and reliable method of evaluating the effect of all those unwanted substances on living organisms. Biomonitoring of the environment is possible by studying the mode of responses of living organisms against the ecological changes (bioindicator species), and their constituent biochemical and molecular components (biomarkers) represent biomonitoring (Sanyal et al. 2015). Employing of biological parameters for assessing environmental perturbation is termed as biomonitoring which has now become a growing subject for research to assess pollution (Bartram and Balance 1996).

Biomonitoring of aquatic ecosystems through the evaluation of biodiversity and their interaction in the natural habitat is one of the important tools for monitoring ecosystem health. The use of indicator organisms in the assessment of water quality depends upon an in-depth knowledge of the ecological tolerance of the concerned organisms. A biological indicator representing a useful biological measure is sensitive enough and can be used for diagnosis, control, prevention, and reclamation. Biomonitoring, the systematic use of living organisms for the assessment of ecological changes, includes several ecological bio-criteria such as molecular, population, community, and ecosystem. This mode of eco-assessment generates complete spectrum of information on holistic water resource management in riverine system. However, the changes in lotic aquatic ecosystems characterized by rapid eco-hydrological variabilities pose difficulty in estimating those parameters, as they cannot reflect the integration of various environmental factors and long-term sustainability of river ecosystems because of their instantaneous nature (Pradhan et al. 2003; Sanyal et al. 2015).

A water quality index (**WQI**) is a numeric expression used to evaluate the quality of a given water body. It is a technique which provides a single number that expresses overall water quality at a certain location and time based on several water quality parameters:

$$\mathbf{SPV} = \frac{\sum_{i=1}^{n}\left(\mathbf{log}^{\mathbf{10\ Pb/n}}\right)}{\mathbf{N}}$$

where

SPV is species pollution values.
Pb is comprehensive pollution values.
n is the number of chemical parameters,
N is the number of study sites.

$$\mathbf{CPV} = \frac{\sum_{i=1}^{n}\mathbf{SPVi}}{\mathbf{n}}$$

where

CPV is the community pollution value.
n is the number of species in a community.

9.6.1 Initiation and Application of Biological Monitoring Program (BMP)

Realizing the urgent need of biological monitoring, the International Union of Biological Sciences (**IUBS**), in its **XXI** General Assembly, held in Ottawa, Canada, in 1982, decided to initiate a worldwide program for identifying and applying biological indicators in environmental monitoring particularly to evaluate the effects of hazardous substances on ecosystems. These programs are with the following objectives:

1. To encourage environmental researchers and managers to develop, standardize, and apply biomonitoring methods indicative of hazardous substances of the environment
2. To generate baseline information of existing methodology of bioindicators
3. To initiate exchange of experience-based knowledge among several like-minded organizations across the globe
4. To publish reference lists along with relevant research information on bioindicators in forms of papers, brochures, practical manuals, etc. for distribution mostly as awareness building program.
5. To promote interdisciplinary actions and develop international collaboration in standardization and execution of acceptable and agreed methods
6. To encourage the scientific organizations in sharing new results concerned with bioindicators among themselves
7. To organize special regional or international symposia, workshops, and seminars for the sharing and dissemination of knowledge

9.6.2 Selection and Application of Bioindicators for Environmental Monitoring

The term bioindicators encompasses a wide spectrum of organisms serving as indicators of environment by way of using or employing the entire organisms through their presence or absence, or utilizing their phenotype features and physiological uniqueness where any of which can serve as an index of their environmental status. Biomonitoring with a bioindicator indicating the general pollution status of the environment, without throwing any light on the exact physical or chemical factors responsible for such environmental quality deterioration, is to be supplemented with appropriate physical and chemical methods to understand the exact reasons for such happenings.

Therefore, different microbes, plants, animals, cell organelles, organs, individuals, populations, biotic communities, and ecosystems displaying different levels of sensitivity can be successfully employed as ecological indicators (bioindicators) to assess and predict environmental change in a timely manner.

9.6.2.1 Microbial Systems

Microbes being fast detectors of the ecological changes by virtue of their sensitivity specifically to some substances can detect harmful substances and also take part in decomposition of pollutants. Alteration of microbial communities and reduction of species diversity can be the result of the presence of specific toxic agents. Bacteria like *Salmonella typhimurium* and fungi such as *Neurospora* and *Aspergillus* have been proved to be very efficient in monitoring genetic effects of physical and chemical agents. Several bacteria such as *E. coli*, *Vibrio* spp., *Aeromonas* sp., *Pseudomonas*, *Clostridium*, *Streptococcus*, etc. have been used for the assessment and prediction of changes in marine environment induced by human activities. Cyanobacteria are used as bioindicators of soil pesticides. Some filamentous fungi, yeasts, actinomycetes, and bacteria are used to monitor oil pollution (oil spillage).

9.6.2.2 Lower Plants: Fungi and Algae

The susceptibility or resistance towards a hazardous substance in the environment varies with different plants species. For example, lichens act as ideal monitoring agents due to their susceptibility and resistance to different environmental effects. There are some lichens which can thrive only in the unpolluted air, whereas others are resistant even to the most polluted systems. Different species of *Lecanora* act as good indicators of a broad spectrum of environment, while lichen thalli can indicate the presence of $\mathbf{SO_2}$ and fluorine in atmosphere. Lichens are also utilized for survey of long life nuclides like cesium **137** and strontium 30, released from nuclear explosions. Various algae such as *Ulva* and *Enteromorpha* have been used as effective bioindicator in monitoring the water quality of rivers and estuaries. Algal species, such as *Cladophora* and *Stigeoclonium*, have shown their efficiency as indicators of heavy metal pollution of water. Some other algae, such as *Dunaliella tertiolecta*, *Skeletonema costatum*, *Criosphaera carterae*, *Amphidinium carterae*, *Cyclotella cryptica*, *Pavlova lutheri*, etc., have been tested for their efficacies as indicators of oil pollution (oil spillage).

9.6.2.3 Applicability of Animal Systems for Biomonitoring

Individual species of an animal, its different organs, or the whole of the biotic community provide data on the accumulation of toxic persistent chemicals in animals. The bioaccumulation and bio-magnification of nondegradable substances through the food chains ultimately reach to the human beings with magnified toxicity as the top representative of the food web which are indicated by selecting a suitable species for routine study. Fish, zooplankton like daphnia, benthic gastropod, aquatic insects, etc. are used to monitor heavy metal and pesticide pollution levels in water. Zooplanktons as rotifers and cladocerans are used as indicators of freshwaters. Earthworms are good bioindicators of soil radioactive pollution.

9.6.2.4 Molecular Biology and Physiology of Living Organisms for Biomonitoring

Cellular and subcellular components have exhibited their flexibility and adaptability towards specific environmental changes and perturbations, representing an excellent components of bioindicators. Both short- and long-term toxicity experimental protocols have been developed in vitro as well as in vivo to monitor changes caused by different environmental agents. Grover et al. (1985) presented an account of monitoring environmental chemicals by chromosomal aberrations in plants. Many animals manifest behavioral responses against environmental changes after detected by their sense organs. An undesirable chemical of the ecosystem imposes severe threats not only to the species populations but also to several organs (endocrine, renal, cardiac, neural, muscular, and digestive) disrupting their functioning as revealed from the observations of the changed morphological, biochemical, or physiological properties.

9.6.3 Rotifers: The Tiniest Zooplanktonic Fauna as Bioindicator Organisms – A Case Study from the Riverine Networks of Southwest Bengal, India

Detection of pollution status by physicochemical ways is not always easy, but sometimes it appears to be very difficult in the remotest areas and expensive too. According to the International Organization for Standardization (**ISO**), environmental monitoring is meant for programed process for measurement and collection of information about the existing status of environment and can be done by both physicochemical and biological "**methods.**" Biological monitoring being an integral part of water quality monitoring includes two of the following categories:

1. The bioassays (early warning or alarm systems, eco-toxicological tests, bioaccumulation tests, eutrophication tests) that are mostly experimental
2. Bio-assessments (analysis through the biological communities) that are observational in approach

Both in turn are linked to the choice of environmental policy makers concerning the updating of "**water quality criteria**" and "**effluent standards**." Biomonitoring or application of biological variables in environmental monitoring activities has often resulted in different interpretations relating to "**biological variables**" and caused a lot of confusion on "**activities**" relating to these aspects (Zwart and Trivedi 1995). A biological indicator is meant to give a useful biological signals having some dimensions, which may be sensitive enough and can be used for diagnosis, control, prevention, and reclamation (Ghetti and Revera 1994). It is possible to judge the nature and degree of pollution of any water body based on the occurrence, abundance, and composition of the inhabiting particular biotic organisms.

Among different groups of zooplankton, due to high population turnover rates, rotifers have appeared to be the most sensitive to changes in water quality. Their community structure not only allows estimates of the level of pollution but also can indicate the trend of general conditions over time (Sladecek 1983). Rotifera, being an important faunal component of freshwater lotic as well as lentic zooplanktonic community, have attracted the attention of several workers globally, with respect to their significance as bioindicators of water quality and also as an indicator of saprobity (Pradhan et al. 2003).

A study has recorded a total of **46** species of Rotifera from **9** study sites in the freshwater riverine network systems of Southwest Bengal, India, formed by the rivers Dwarkeswar, Shilabati, and Kansai (Pradhan and Chakraborty 2006). All the documented Rotifera species were categorized as per the established scheme for bioindicator species, viz., eutrophic species, oligotrophic species, acidophilic species, mixohaline species, alkaline mesotrophic species, taxa preferring special water, temperate species, worm stenothermal species, cold stenothermal species, and eurythermal species. The physicochemical parameters of different study sites where the rotiferan bioindicator species inhabit were compared with the international standards for permissible limit to find out the relationship between the intensity of pollution and occurrence of rotifers. Rotifera comprised of an important faunal component of littoral and limnetic invertebrate communities in freshwater environments. Rotifera has been considered as good indicators of saprobity (= organic pollution manifested in **BOD5′** dissolved oxygen content and specific communities of indicator species). Hakkari 1972; Radwan 1976; Fuller et al. (1977), Maemets (1983) and Sladecek (1983), advocated for the significance of bioindicator species of in monitoring the water quality, trophic status and environmental toxicity.

In fact, on applying rotiferan zooplankton as bioindicators for the first time, Kolkwitz and Marsoon (1902) set up "**saprobien system**" to define the quality of surface waters mainly on the presence of indicator species, and this system is still wildly used forming the basis for a series of biological indices (De Pauw et al. 1992). Subsequently, Kolkwitz (1935) listed some species as polysaprobic, alpha mesosaprobic, beta-mesosaprobic, and oligosaprobic. Wetzel (1959) listed two polysaprobic species as tamesosaprobic and four species as oligosaprobic. Sladecek (1983) provided an excellent account of **625** species of Rotifera after recording from Czechoslovakia as indicators of water quality making relevant remarks on saprobity, saprobic valence, indicative weight of different species, saprobic index, and pollution. In addition, other notable contributions had dealt the role of Rotifera as bioindicator highlighting their relationships with **pH** (Berzins and Pejler 1987), temperature (Berzins and Pejler 1989a), trophic degree (Berzins and Pejler 1989b), oxygen content (Berzins and Pejler 1989c), water color (Berzins and Pejler 1989d), and substrate and habitat (Pejler and Berzins 1989, Pejler and Berzins 1993; Giri and Chakraborty (2012); Giri et al. (2005); Giri et al. (2008)).

In this study, the temporal and spatial distribution patterns were studied in relation to major ecological parameters pertaining to riverine ecosystem. All the documented Rotifera species were categorized as per the established scheme for bioindicator species, viz., eutrophic species, oligotrophic species, acidophilic species, mixohaline species, alkaline mesotrophic species, taxa preferring special water, temperate species, worm stenothermal species, cold stenothermal species, and eurythermal species. On the basis of observation of diversity index, the range of pollution in rivers and streams can be assigned into three undermentioned categories (Wilhm and Dorris 1968): **H^{-} (Shannon index: condition of water of diversity) >3** clean water; **1–3** moderately polluted, and **<1** heavily polluted. In the present study, the rotiferan population registered a highly significant inverse relationship with water current which corroborated the findings of Reinhard (1931) and Eddy (1934).

Hofmann (1977) opined that temperature exerts a significant influence on population dynamics of rotifer not only because of its direct control on embryonic development but also because it is an important characteristic of the determinative situation of the environment. The correlation between Rotifera and temperature showed also significant positive relationship in most of the study areas. The **pH** governed the distributional transport and fate of heavy metals in an aquatic system (Whitton and Say 1975). The alkaline **pH** was favorable for the growth of aquatic vegetation (Westlake 1975). Comparatively lower **pH** during summer months was supposed to be due to higher decomposition activities of organic matter coupled with higher temperature and lower water depth. In this study, **pH** did not show any definite seasonal trend, and **pH** values ranged from **6.1** to **7.9**, and thus in most cases, it remained to either in acidic or in alkaline range, and Rotifera exhibited both significant and insignificant direct and indirect correlations with **pH** as revealed from correlation coefficient analysis (Giri et al. 2003; Pradhan et al. 2003, 2008; Pradhan and Chakraborty 2006).

According to Berzins and Pejler (1987), **pH** had no direct effect on rotifers even though it appeared to be as an important parameter in explaining the distribution of different species. Besides species-specific study, it was quite difficult to draw any definite trend between different zooplankton groups and **pH**. Species-wise study of different rotifer species revealed that different species displayed different relationships with **pH**. **Alkalinity** of the water by possessing hydroxyl ions capable of combining with the hydrogen ion neutralizes a strong acid (Trivedy and Goel 1984). The species with well-developed lorica such as *Brachionus* and *Keratella* built higher population during the period when the alkalinity was high (Dhanpathi 2000), but in the present observation, although the water conditions were neither acidic nor alkaline, the genus *Brachionus* and *Keratella* exhibited positive relationship with alkalinity. Sharma (1992) stated that the Rotifera fauna of West Bengal included various acidophilic species, **viz**., *K. cochliaris* and *B. patulus*, whereas *B. bidentata*, *B. rubens*, and *Lecane lunaris* have been regarded by him as alkalophilic element. Several indicator species of Rotifera recorded from Indian inland waters were categorized by Sharma (1996). Based on the affinity for specific water bodies following categories of Rotifera have been made.

1. **Eutrophic species**: Those species which are likely to inhabit in highly nutrient-containing water bodies, **viz.**, *Brachionus angularis*, *B. bidentata*, *B. calyciflorus*,

B. caudatus personahis, *B. falcatus*, *B. rubens*, *Keratella tropica*, *Asplanchna priodonta*, *L. curvicornis curvicornis*, *Lecane (Monostyla) bulla*, *L. (M.) lunaris*, *Polyartltra vulgaris*, *Pompholyx sulcata*, and *Filinia longiseta.* Most of these species were designated as eutrophic indicators in India and elsewhere in the world (Sladecek 1983; Saksena 1987; Sharma 1996). Out of these rotiferan species, *Brachionus angularis*, *B. calyciflorus*, *B. rubens*, and *Filinia longiseta* have been reported to inhabit in hypereutrophic water body (Sharma 1996).

2. **Oligotrophic species**: Those species which are likely to inhabit in low nutrient-containing water bodies, **viz.**, *B. falcatus*, *Keratella cochlearis*, *Keratella tropica*, *Lepadella (Lepadella) ovalis*, *L. (L.) leontina*, *L. (L.) nana*, *L. (M.) decipiens*, and *Asplanchna priodonta*.
3. **Acidophilic species**: Those species which are likely to inhabit in acidic water bodies, **viz.**, *B. quadridentatus* and *Ellc allis dilatata*.
4. **Alkaline mesotrophic species**: Those species which are likely to inhabit in alkaline and moderately nutrient-containing water bodies, **viz.**, *Brachionus angularis*, *B. bidentata*, *B. caudatus personatus*, *B. rubens*, *B. calyciflorus*, *B. falcatus*, *B. forficula*, *Keratella tropica*, *Lecane (L.) curvicornis curvicornis*, *Lecane (Monostyla) bulla*, *L. (M.) lunaris*, *Polyartlzra vulgaris*, *Pompholyx sulcata*, and *Filinia longiseta.*
5. **Worm stenothermal species**: Those species which are likely to live in narrow range of worm water, **viz.**, *B. bidentata*, *B. forfiella*, *B. falcatus*, *Keratella tropica*, *Beaucllampiella elldactylota*, and *L. (M.) stenroosi.*
6. **Eurythermal species**: Those species which are like to live in wide range of temperature variation, **viz.**, *Brachionus angularis*, *B. calyciflorus*, *B. rubens*, *Lepadella (Lepadella) ovalis*, *L. (L.) hastate*, and *Polyarthra vulgaris.*

Pejler (1983) mentioned that along a trophic scale, the number of planktonic rotifer species successfully increased up to mesotrophic condition, after which the numbers declined till hypereutrophic phase. On the basis of scales as developed by Wilhm and Dorris (1968), nine different study sites located on three freshwater rivers, through six seasons of two consecutive years, showed Shannon index of diversity of rotiferan community between **1** and **3**. Based on such information, the water of such water bodies can be regarded as moderately polluted (Pradhan and Chakraborty, 2008; Pradhan et al, 2003).

9.6.4 Biomonitoring by Aquatic Insects

Ecological changes in an ecosystem because of anthropogenic activities can be assessed from taxonomic, functional, and phylogenetic diversity, by the computation of different community indices such as richness (Astorga et al. 2011; Ligeiro et al. 2013; Brasil et al. 2019), by the recording of species composition Montag et al. 2019), by the abundance of individuals (Paiva et al. 2017), by beta diversity (Cunha and Juen 2017; Brasil et al. 2017), and by functional diversity (Péru and Dolédec

2010). In addition to the community-level approach, it is also possible to assess the changing environmental condition by the presence or absence of species in the course of population studies. Some groups like aquatic insects, such as Ephemeroptera, Coleoptera, Hymenoptera, Plecoptera, Hemiptera, and Trichoptera, have revealed differential power of tolerance in the disturbed or polluted aquatic systems losing the number of species or individuals (Siegloch et al. 2017). Thus, it is important to identify which environmental factors can affect or benefit aquatic insects, since environmental monitoring with the help of aquatic insects is based on the distribution of species and their ability to respond to different environmental conditions (Roque et al. 2008). Freshwater environments in the tropics, the most threatened landscape of the world, differ ecologically from those in temperate zones in their physical, chemical, and biological attributes (Kwok et al. 2007) and are now in need of proper protection and effective conservation. Eco-monitoring of the environmental changes in the rivers and streams with the help aquatic insect community commands more attention from environmental managers. The establishment of direct relationship between aquatic insect communities and environmental predictors has become important to undertake a multi-scale analysis between the lotic freshwater systems, riparian zone, and regional landscape. Conventional biotic indices such as richness index, composition of species, and abundance or density of individuals along with the knowledge base of functional and phylogenetic diversity of aquatic insects can be used to measure changes in ecosystem services and loss of evolutionary lineages.

Three different scales have been noted at which environmental alterations due to the interventions of human beings that occur and affect aquatic insect communities. These scales are as follows: (**i**) impacts are limited at the regional level and changes are brought about due to changes in the land use in a region that drains wastewater into an freshwater system (Allan and Johnson, 1997; Allan et al. 1997; Allan 2004); (**ii**) environmental changes are caused by the impacts from the riparian zone, located along the margins of freshwater systems, such as deforestation-mediated ecological disturbances, erosion, reduction in the supply of allochthonous nutrients, etc. (Naiman and Decamps 1997); and **(iii**) impacts on directly receiving wastewater such as disposal of sewage in the river or stream (Martins and Pereira 2017). All these scales individually or synergistically cause significant changes in aquatic biota and, consequently, in ecosystem services (Allan 2004). Based on the baseline research information of the impact of the environmental changes on the ecology of aquatic insects (variations in soil use, scale of change, diversity metrics, and taxonomic groups), it is possible to throw light on the present ecological status of the riverine ecosystem and also to predict future environmental consequences. Several background information such as (**i**) climate region (tropical or temperate), (**ii**) local (physicochemical variables of the water, channel structure) and regional (changes in the land use, growth, and extent of riparian zone) environmental predictors, (**iii**) groups of entomofauna (Hemiptera, Ephemeroptera, Trichoptera, Odonata, Coleoptera, Diptera, etc.), and **(iv)** different indices of diversity (species richness, evenness, relative abundance of individuals, etc.) are required for the biomonitoring program of the insects.

A combined analysis of predictors at a local and regional scale (instream and landscape) has appeared to contribute effectively to the relationships between the environmental predictors with aquatic insect communities. The influence of the landscape characteristics (width of riparian vegetation, relief, and type) and stream characteristics (water quality parameters, volume and currents of water, size, width, etc.) affects the ecological conditions (concentrations of nutrients, increase in water temperature, degradation of riparian forest, and an increase in the flow rate of sediment) and, consequently, the aquatic communities in a stream (Allan and Johnson 1997; Steinman and Denning 2005; Macedo et al. 2013).

Besides, for the evaluation of the roles of aquatic insects in the biomonitoring of the riverine ecological changes, an important aspect is the selection of the most suitable taxonomic group based on their sensitivity, tolerance, and resistance of organisms to environmental variations and ecological stresses for pollution which vary based on the environmental conditions (Martins and Pereira, 2017). Among these groups, Ephemeroptera, Plecoptera, and Trichoptera (**EPT**) are used as the most acceptable groups to play as bioindicators of lotic freshwater systems (Vinson and Hawkins 2003).

9.6.5 Eco-biomonitoring of a Transboundary River in India by Molluskan Community Indices: A Case Study from the Riverine System from the Southwest Bengal, India

In order to become an ideal bioindicator, an organism must have some suitable characteristics (Hilty and Merenlender 2000; Zheng and Liu 2010; Füreder and Reynolds 2003) as mentioned below:

1. Taxonomic simplicity in order to enable even nontechnical person to recognize and identify the species
2. Wide range of regional, national, and even worldwide distribution
3. Preference towards local habitats with low mobility
4. Well-documented ecological attributes
5. Occurrence in higher density
6. Suitability for its use both in field and laboratory experimental studies
7. Higher sensitivity to ecological changes

In a recent ecological study, emphasis on detailed environmental assessment of water, soil, diversity, density, distribution, and community interactions of benthic mollusks have been made at five different contrasting ecozones (study sites **I**, **II**, **III**, **IV**, and **V**) on Subarnarekha River, a major transboundary river of India during six seasons of **2** consecutive years (July 2012 to June 2014). Major physicochemical parameters (**pH**, temperature, dissolved oxygen, hardness, etc.) and (6) heavy metals of water and soil have been estimated through six different seasons of **2** consecutive years. Heavy metal pollution of rivers is mostly caused by industrial, domestic, urbanized, and agricultural wastes. The persistence toxicity of heavy metals and their bioavailability have established them as potential pollutants. Major heavy metals such as **Hg**, **Pb**, **Cr**, and **Cd** by virtue of their toxic effects even at minimum concentrations in the bioavailable form can enter the food chain and produce a range of metabolic and physiological disorders (Zheng and Liu 2010; Loviov 1999). However, metals (**Fe** and **Zn**) which are needed for the normal development of living beings can be detrimental if their concentrations exceeded above their threshold values. Metals after being reached to the river water with municipal or industrial bind with particulate matters and assuming more weight settle down to the bottom to become a part of the sediments (Suthar et al. 2009). The contamination of aquatic and soil environments with such toxic materials impose serious threats to aquatic ecosystems, agriculture, and human health (Masindi and Muedi 2018).

The Subarnarekha River, a major transboundary river in the Eastern India, traverses through different landscape areas (mines, industrial field, agricultural field, forest, etc.) of three states of India, viz., Jharkhand, Odisha, and West Bengal, before ending to **Bay of Bengal** at the border of the two states of Eastern India, West Bengal and Odisha. As the consequence of the extensive mining and mineral processing activities for the industries, devastating environmental degradation has resulted in the upstream of this river.

During monsoon, the open and exposed earthen material flows into the river as runoff water and thereby increase the load of suspended solids and heavy metals in the water. Application of biological organism as an indicator of community or environmental changes has been proved to be the most effective in providing explanation of the cause and effect of pollution in recent years (David and Philips, 1970).

The trend of occurrence in respect of concentration of heavy metals was found to be in tune of **Fe>Cu>Zn>Pb>Cr>Cd** at **SI** to **SV** except **SII** where such trend was exhibited as **Cu>Fe>Cr>Zn>Pb>Cd**. The pollution load index and geoaccumulation index have revealed different modes of pollution loads in the surface of bottom sediments. A number of biotic indices like species diversity index and dominant index were found to be maximum during postmonsoon season, whereas species richness index and species evenness index were recorded maximum during monsoon season. Macrobenthic invertebrates inhabiting in the bottom of the freshwater bodies can play an important role in detecting the quality of water body by acting as a reliable bioindicator due to their longevity, site-specific habitats, and least mobility (Zheng and Liu 2010).

Among benthic invertebrates, mollusks play an important role as bioindicators due to their susceptibility to contaminants (Loviov 1999) and their power of tolerance against altered ecological conditions (Edmondson et al. 2010; Gupta and Singh 2011). Macrobenthic invertebrates, especially mollusks with higher species diversity and distribution, are being used in the evaluation of effect of stress based on their community behavior, density distribution, and environmental sensitivity (Sharma and Saini 2016). This group of bottom-dwelling animals sharing a major portion of benthic population and belonging to the higher strata of benthic food chain systems can frequently reflect any effect on benthic community in response to environmental contamination, geographical changes, and similar other natural or man-made modifications. Organisms belonging to this group are mostly sedentary, colonial, and ecosystem-specific. By virtue of these qualities, benthic organisms are considered ideal for environmental impact assessment and have been accepted and utilized in pollution investigation throughout the world. The present study was based on seasonal variation of concentrations and mode of contamination of heavy metal in sediments and water from different sites of Subarnarekha River of India with an emphasis on determining the roles of benthic mollusks for biomonitoring of the ecological changes in a river ecosystem (Pakhira and Chakraborty 2016, 2018; Chakraborty et al. 2021)).

9.6.6 Different Biotic Indices in Temporal and Spatial Scales

In an intra-community assemblage, species or species groups normally controlling the energy flow and strongly affecting the prevailing environment of all other species in a community are known as ecological dominant (Chakraborty and Choudhury 1994). The degree to which dominance concentrates in any species or species groups can be expressed by an appropriate index of dominance which tends to show inverse relationship with species diversity index which in other way usually exhibit direct variation with species richness index (Odum 1971). Among the five study sites, the dominance index was found to be maximum at **SI** followed by **SII**, **SIV**, SV, and SIII.

The species diversity index was recorded highest at **SV** followed by **SIII**, **SIV**, **SII**, and **SI**. The maximum richness index was found at **SV** (**1.83**) followed by SIII (**1.47**), **SIV** (**1.28**), **SII** (**1.04**), and SI (**0.67**). The maximum evenness index was derived at SIII (**0.925**) and that of minimum was seen at **SI** (**5.29**). The maximum values of dominant index were found during postmonsoon season, whereas minimum values were recorded during monsoon season. Maximum species diversity index was observed in monsoon season in all study sites except **SIV** and registered maximum in postmonsoon season, whereas minimum species diversity index was noted in pre-monsoon season in all study sites excluding **SIV** where minimum was found in monsoon. The maximum species richness index was found in monsoon, and minimum was noted in postmonsoon for all the study sites. Species evenness index showed maximum during monsoon season for **SI**, **SIII**, and **SV** and during postmonsoon for **SII** and **SIV** while minimum was value was recorded during monsoon at study sites **I**, **III**, and **V** and minimum during monsoon season at study sites **II** and **V** (Pakhira and Chakraborty 2016, 2018; Chakraborty et al. 2021).

9.6.7 Different Indices Based on Heavy Metals

9.6.7.1 Contamination Factor (CF)

Contamination factor is used to assess the pollution load of the sediments with respect to heavy metal pollution. **Contamination factor (CF)** values of different heavy metals recorded at different study sites displayed different results after being influenced by the prevailing ecological variables. There are four grade ratings on the basis of **CF** values (Hakanson 1980). All study sites displayed low **CF (CF < 1, Class 1)** to moderate **CF (CF 1 = CF < 3, Class 2)** during different seasons, indicating unpolluted to moderately polluted nature of the sediments (Pakhira and Chakraborty 2018; Chakraborty et al. 2021).

9.6.7.2 Pollution Load Index (PLI)

Pollution load index is an effective tool for assessing and comparing the sediment quality. According to Mohiuddin et al. (2010), **PLI = 0** indicates perfection, **PLI = 1** indicates baseline level of pollutant, and **PLI > 1** represents progressive deterioration of sediment. All the study sites revealed the **PLI** value as greater than one which reflects the polluted nature of the sediments. The maximum and the minimum **PLI** values as recorded from **SII** and **SV**, respectively, were due to the discharge of industrial effluent and anthropogenic activities carried out at the upstream region of the river (Pakhira and Chakraborty 2018; Chakraborty et al. 2021).

9.6.7.3 Geoaccumulation Index (Igeo)

The geoaccumulation index was introduced by Muller (1979) for determining the extent of metal accumulation in the sediments. It consists of seven grade classification system of sediments from unpolluted to extremely polluted nature of sediments. Geoaccumulation index values obtained for different metals at different study sites are presented. Among the five study sites, **SI** showed **1 < Igeo <2** representing moderate polluted nature of the sediment. **SII** revealed **0 < Igeo <1** reflecting the unpolluted to moderate polluted nature of the sediments, and **SIII**, **SIV**, and **SV** showed **Igeo <0** representing the unpolluted nature of the sediments (Pakhira and Chakraborty 2018; Chakraborty et al. 2021).

9.6.7.4 Justification of Considering Mollusks as Bioindicators

Biomonitoring gives the direct evidences of ecological changes that occurred in the aquatic ecosystem due to environmental pollution. There are several ways to find out the information on the biomonitoring of aquatic metal pollution which gives the potential effects and actual toxicities. In this study, different community indices of mollusks like index of dominance, species richness index or variety of indices, species diversity index, species evenness index, different heavy metal indices such as contamination factor, pollution load index, and geoaccumulation index have been used for biomonitoring and assessing the ecological status of Subarnarekha River.

The maximum values of contamination factor, pollution load index, and geoaccumulation index were found in the upstream region (**SI** and **SII**), and such intensity of heavy metal concentrations was seen gradually decreasing at the rest of the study sites (**SIII**, **SIV**, and **SV**) located in the downstream of this river. From the earlier observations of Muller (1981), it can be inferred that industrialization and mining practices in the upstream region might increase the values of contamination factor, pollution load index, and geoaccumulation index, and also those anthropogenic activities were principally responsible for the higher existence of heavy metals in the downstream region.

These findings have been substantiated by the biotic indices as maximum species diversity indices from **study site V** have confirmed the inverse relationship of pollution stress with biotic diversity. Therefore, alongside recording the molluskan species in the entire stretch (around **240 km**) of Subarnarekha River, different eco-geo-biological indices have appeared to throw more insights on assessing the ongoing environmental perturbations in a lowering aquatic ecosystem mainly heavy metals (Pakira and Chakraboty 2018; Chakraborty et al. 2021).

9.6.8 Biomonitoring of Wetlands by Zooplankton: A Case Study from the East Kolkata Wetland, West Bengal, India

Wetlands, one of the most productive life-support systems across the globe, have become a threatened landscape mostly because of a multitude of human activities. A recent study conducted on four selected wetlands of East Kolkata Wetlands (**EKW**), a Ramsar Site of the state of West Bengal, India, with five study sites, **viz.**, **study site I**, **study site II**, **study site III**, and study **site IV**, had verified and tested the scopes and utility of application of a biotic index developed based on the qualitative distribution of **3** major taxa of zooplankton (Rotifera with **5** genera and **11** species, Cladocera with **6** genera, and Copepoda with **4** genera) for biomonitoring.

The biotic indices like **CPV** and **SPV** have been calculated. Computation of index of similarity has revealed maximum similarity between study **site** I and study **site IV** for total zooplankton, Rotifera, Copepoda, and Cladocera as **58.8%**, **60%**, **66.67%**, and **85.71%**, respectively. As population density of total Rotifera exhibited highest density at the eco-restored wetlands (study **site III** and study **site IV**), ecological stabilities with least disturbances in the water body are reflected by the dominance of both Cladocera and Copepoda (**study site I**). The community pollution value (**CPV**) calculated from the distribution of zooplanktonic species indicates the higher intensity of pollution (Jiang 2006, Guo et al. 2010) at **SII** by **study site III**, study site IV, and **study site I** during July **2008**–June **2011**. The species pollution value (**SPV**) was computed based on the basic ecological information on zooplanktonic taxa. Also pointed out was the differential pollution loads of different wetlands (Sanyal et al. 2015).

9.6.9 Biomonitoring of Aquatic Ecosystems with Molecular Markers: A Case Study from the Southwest Bengal, India

Monitoring of global warming-mediated devastating ecological effects on freshwater wetland ecosystems through a long-term eco-biological studies of a freshwater benthic molluskan species have revealed that changes in biochemical entities bear a direct relationship with the ongoing ecological changes from molecules to ecosystem (Maity Dutta et al. 2014, 2018). Adverse ecological conditions due to the continuous rise in temperature tended to impose stress on the aquatic faunal components including the benthic fauna by causing reactive oxygen species and oxidative stress-mediated damages to cells, and the affected fauna in response evolve a variety of defense mechanisms to overcome both external and internal environmental challenges by metabolic changes in order to maintain cellular homeostasis (Fabbri et al. 2008; Mizrahi et al. 2014). It has been experimentally established that the ecosystems having higher biodiversity can adjust more temperature-mediated stress than those with less biodiversity (Wood et al. 2017). After being stressed, **reactive oxygen species (ROS)** are continually generated as consequences of normal metabolic pathways, and degradation of **ROS** levels is controlled by delicate cellular control mechanisms (Halliwell and Gutteridge 2007). All information pertaining to the temperature stress have advocated in favor of cellular adaptation which is supposed to have been caused by the antioxidants and some drug-metabolizing enzymes which in turn trigger the cells to produce antioxidant enzyme systems and free radical scavengers like nonprotein thiols and reduced glutathione (**GSH**) which are considered as common biomarkers used in environmental monitoring (Doyotte et al. 1997; Regoli et al. 1998; Chainy et al. 2016).

Emphasizing heat shock protein 70 (**HSP70**) as one of the potential biomarkers for environmental stress in fishes, mollusks, etc. (Wepener et al. 2005; Liu and Chen 2013; Maity Dutta et al. 2014; da Silva Cantinha et al. 2017), a recent study on screening and identifying some biochemical entities including **HSP70**, catalase (**CAT**), superoxide dismutase (**SOD**), reduced glutathione (**GSH**), and glutathione reductase (**GR**) has established their efficacies as dependable biomarkers as a measure to evaluate the impact of the temperature-induced stress on *Bellamya bengalensis* (Lamark 1882), a highly representative freshwater benthic molluskan gastropod in (Maity Dutta et al. 2014). Earlier studies on population density and reproduction potentiality of this gastropod species have revealed stress withstanding ability (Raut 1981). Owing to increasing concern of global climate change, temperature rise is of great interest to any aquatic environment developing extreme stressful ecological states to the poikilothermous animals like gastropod mollusks.

This study had unearthed some interesting facts relating to potentiality of the molecules and the anti-oxidative metabolic network as the biomarker in the studied two contrasting ecozones: a natural and an eco-restored forest-wetland ecosystem, named Gurguripal, in the District of Midnapore (West), of the state of West Bengal, India, in the eastern part of India. **10–20**-fold increases in **CAT**, **SOD**, and **HSP70** protein expressions paralleling to their increased enzymatic activities were recorded after exposing the faunal component (benthic mollusk: *Bellamya bengalensis* (Lamark 1882)) in different temperature stresses. The reduced **GR** coupled with increased glutathione peroxidase (**GPx**) has pointed out distinctly on the oxidative damage of cells as evident by an increase of malondialdehyde (**MDA**) level within the damaged tissues leading to higher mortality. Changes in **SOD** and **CAT** activities indicate more activation of physiological processes which scavenge the **ROS** generated because of its exposure to heat stress. However, when mortality increased at different time points, these enzyme activities exhibited a decreasing trend at higher temperature stresses (**36 °C–72 h** and **38 °C–72 h**) and thereby failed to repair the damaged tissues from the action **ROS** and there resulted higher mortality of the animals.

The systematic extrapolation of the findings of this experimental study subjecting the gastropod mollusk at different temperature stresses has reflected changes in the **HSP** and antioxidant functions which have generated scopes for the better understanding of the climate change- and global warming-related adaptive responses in the biological systems. The **HSP70** exerting its important role in the adaptive mechanism play a fundamental role of **HSPs** in the regulation of protein synthesis, protein folding and targeting, and kinetic partitioning between folding and thereby make them very dependable regulators within the cell (Roberts et al. 2010).

Based on this study, it is hypothesized that heat can exert stress alone or in association with some prevailing physicochemical parameters in an aquatic ecosystem. The synergistic effects of these factors are magnified with the change of time and with the degree of exposure of such stresses. But withstanding such stresses for a certain period of time, the adaptive ability of the organism against stress get exhausted, and the stressed animal ultimately succumb to death. It is also accepted that global warming- and climate change-mediated stresses on living organism help explain the roles of several cellular organelles, thereby recognizing some biomolecules as biomarkers in monitoring the ecological changes of aquatic system (Maity Dutta et al. 2014, 2018).

9.6.10 *Monitoring and Assessment of Thermal Stress by Hsp70 and MnSOD of Freshwater Gastropod* **Bellamya bengalensis** *(Lamark 1882): A Case Study from the Southwest Bengal, India*

The atmospheric temperatures are expected to rise by **1.4–5.8 °C** by the end of this century as a result of global warming (Parry et al. 2007). The exposure of organisms to temperature stress activates radical in oxidative stress, especially in the presence of heat. Global climate change-mediated environmental pollution can lead to an increase in the temperature of water bodies, which in turn alter several physico-chemical expressions of different heat shock proteins (**HSPs**) (Piano et al. 2002; Dieterich et al. 2013). **HSPs** being ubiquitous chaperones help refold stress-induced denatured proteins (Nollen and Morimoto 2002; Wang et al. 2013) and also are considered as important biomarkers in organisms exposing themselves to ongoing pollution or thermal stress in nature (Hofmann et al. 2000; Metzger et al. 2012; An et al. 2014). Besides, heat-induced generation of reactive oxygen species (**ROS**), i.e., **superoxide**, $\mathbf{H_2O_2}$ and $\mathbf{OH}^-$ radicals, has been implicated in stress-related molecular response and acclimatization (Verlecar et al. 2008). Superoxide dismutase (**SOD**) is the chief regulator of **ROS** and a producer of $\mathbf{H_2O_2}$ from $\mathbf{O_2}$ (Fridovich 1995; Landis and Tower 2005). Both of these proteins are primitive and universal in their structure and actions in organisms (Monserrat et al. 2007).

Hsp70 being a molecular chaperone help in proper folding of proteins so that the biomolecules can maintain stability and thereby act as an important mitochondrial transporter protein (Hofmann et al. 2000). However, manganese superoxide dismutase (**MnSOD**) also acts as a scavenger of superoxide which is commonly occurring free parameters like salinity, heavy metals, biological oxygen demand (**BOD**), chemical oxygen demand (**COD**), etc. of the aquatic environment (Ficke et al. 2007; de Bij et al. 2006). Scavenging of superoxide is one of the most important stress adaptations because the presence of $\mathbf{O_2}$ and $\mathbf{H_2O_2}$ can also lead to the formation of the highly reactive and damaging hydroxyl radical (**OH·**) (Halliwell and Gutteridge 1986). The free radicals can perturb structures of all cellular components such as membranes and resulting mutagenic **DNA** breakage (LaVerne and Pimblott 1993).

The crucial balance between the exogenous prooxidant factors and the antioxidant defense system of an organism may be evaluated to assess the impact of the environmental stressors on the ecological system (Andersen et al. 2006). **SOD** and **Hsp70** have been after being exposed to thermal stress (Liu and Post 2000; Banerjee et al. 2009). The combined effects of water temperature and other environmental factors have been shown to influence on the expression of **Hsp70** (Wang et al. 2012; Izagirre et al. 2014). In a recent study (Maity Dutta et al. 2018), a freshwater molluskan species, *Bellamya bengalensis* (Lamark 1882) (Gastropoda: Viviparidae), was selected as a test animal to evaluate the impact of the physicochemical properties of water, environmental pollution, and heat stress in two wetlands [**study site I** (**SI**) and **study site II** (**SII**)], one eco-restored, devoid of human interference (**SI**) and the other wetland sustaining human impacts (**SII**).

Besides biomarker (**SOD and Hsp70**) expression studies, the survivability, mortality, and stress adaptability in this experimental species were evaluated during summer and winter seasons. The research findings of this study have improved the understanding of the use of suitable biomarkers in a commonly occurring aquatic fauna so that ecological consequences because of global environmental stresses can be assessed. Assessment of mode of expression of biomarkers such as **70-kD** heat shock proteins (**Hsp70**) and manganese superoxide dismutase (**MnSOD**) in response to the heat stress on the freshwater molluskan species *Bellamya bengalensis* (Lamark 1882) explains the molecular basis of adaptive response manifested by the studied species against increased experimental temperatures (**32–40 °C** for a period of **24–72 h**). Simultaneously performing the immunoblotting of **MnSOD** and **Hsp70** from their digestive glands and the recording of mortality rate of *B. bengalensis* at regular intervals during the period of heat stress have revealed the relationship of stresses and the biomarkers.

The expression of **Hsp70** was observed minimum at lower thermal stress, which showed a rising trend with the increase of temperature. The higher **Hsp70** levels do not show direct and positive relation with the survival of the concerned animals. In contrast, recognizing the expression levels of a universal free radical scavenger like **MnSOD** levels as a potential bioindicator of adaptive response of the animal species like *Bellamya bengalensis* towards its survivality. The mortality rate of *B. bengalensis* from **SII** was found to be always less from that of **SI** animals in similar experimental condition. Both the **Hsp70** and **MnSOD** levels also showed no significant alteration in response to elevated temperature for animals collected from **SI** during the summer except the **Hsp70** expression at **38 °C** which was increased by **1.8–2.7** fold at different periods of exposure. The **Hsp70** expression in *B. bengalensis* from **SII** also demonstrated a gradual increase in **Hsp70** levels over the control in winter. However, the upregulation of **Hsp70** in treatment at **SII** never exceeded by a **2.5**-fold increase at both **36 °C** (**48 h**) and **38 °C** (**48 h**). The expression of this protein exhibited higher results with respect to control, but the duration of the dependent response was not prominent.

In contrast, snails collected from **SII** during the summer had demonstrated a significant upregulation of both **Hsp70** and **MnSOD** and had an almost 4-fold increase (**36 °C** for a span of **48 h**) and a **2.5**-fold increase (**38 °C** of the duration of **48 h**), respectively. It can be concluded that longer durations at higher temperatures result in reduced protein expression in the present study. **MnSOD** levels showed a considerable increase during an exposure of **24** and **48 h** over untreated controls for both sites and seasons. **MnSOD** levels of *Bellamya* exhibited markedly higher levels at **SII** than at **SI** in winter. Moreover, the increase of **MnSOD** was sustained through **72 h** of treatment when maximum mortality was observed. In summer, the expression of **Hsp70** of studied animals from both **SI** and **SII** did not indicate any alteration in protein levels. The basal levels of **Hsp70** protein in control (laboratory stress unexposed) snails of both sites were found to be notably higher in summer than that of winter. As a result, a further expression of this protein was found not to be very significant due to the laboratory temperature exposure to these snails. The study depicts more acceptable results from the observation field-derived component in comparison to laboratory-derived data on the stressed animals. Though these seasonal protein expression variations are mainly attributed by the temperature change, we have to take into account the interactive role of other physicochemical variables of the corresponding environment.

Owing to the higher incidence of mortality in *Bellamya* after being subjected to elevated temperature at **40 °C** in specimens collected in winter, **Hsp70** and **MnSOD** levels could not be measured. Response to stress is a key factor for survival of an organism (Storey 1996; Gidalevitz et al. 2011). This study also revealed the susceptibility of *B. bengalensis* inhabiting at both sites to mortality by thermal stress. However, at **SII**, which has been used regularly for domestic purpose (washing, bathing, etc.), results in greater stress adaptation in aquatic animals. Probably for this reason, water **pH**, alkalinity, **TDS, TSS, BOD**, and **COD** were recorded as consistently higher in **SII** compared to **SI**. The higher **BOD** and productivity in **SII** were likely also responsible for the lower **DO** concentration in this site. In addition, unlike **SI, SII** is a closed and isolated water body which does not experience the water recirculation and passage with other water bodies. The time- and temperature-dependent changes in stress responses were less prominent at **SII** than **SI** during summer.

But the responses **SI** and **SII** in winter were found to be similar. Both the increase in **MnSOD** and **HSP70** appeared to be time-dependent at different temperatures during winter. Since the basal values of both proteins were higher in summer compared to winter, further elevation of temperature in laboratory condition resulted little change in *B. bengalensis* collected during summer. This observation indicates that natural temperature changes due to seasonal variations in association with the corresponding physicochemical parameters had measurable effects on **Hsp70** and **MnSOD** expressions. The responses generated due to the seasonal variation were similar to the results noticed in laboratory temperature experiments. It reveals the ubiquitous impact of heat stress adaptation in these animals.

The increase in both **MnSOD** and **Hsp70** is interpreted as adaptive changes against heat stress. In summer, there is a comparatively small difference between the ambient water temperatures of both sites and the temperature applied for inflicting thermal stress to *Bellamya bengalensis*. As a result, the impact of the thermal stress alone is much lower in summer in comparison to that of winter. It was further observed that when exposed to elevated thermal stress, the snails did not have mortality probably due to their preadaptation to apparently polluted water. In this context, it can be inferred that the heat shock response can be induced in *B. bengalensis* through induction of **Hsp70** when the thermal stress is substantial. At lower thermal stress levels, induction of **Hsp70** was found to be at minimum levels, whereas higher **Hsp70** levels did not show any relation to survival or adaptation. The **MnSOD** levels, as an indicator of survival in the studied species, reflect variability in the tolerance level from lower-intensity stresses to poor quality water condition. Thus, measurement of **MnSOD** levels is supposed to serve as the potential biomarker in a freshwater bioindicator species *B. bengalensis*.

The significance of the present study focuses on the dependent biomarkers to predict environmental stresses imprinted on a bioindicator species. It is noticed in the present experiment that the **SII** animals were acclimatized and adapted to an array of pollutants and thereby expressed more tolerance prior to their utilization in the heat stress experiments. It can be hypothesized that the preadaptation to a certain degree of cumulative stress may provide some resistance against adverse stress condition. In the future, the best possible laboratory experimental schedule resembling natural environmental condition may open further scope for the understanding of natural stress adaptation. In view of the present scenario for global warming, extrapolation of this research outcome may provide the groundwork for further studies to explore the strategy of natural and long-term stress adaptation against sustained environmental threats (Maity Dutta et al. 2018).

9.7 Documentation of Biological Components

9.7.1 Collection and Recording of Macrophytes

Macrophytes constituting an important green biomass of any freshwater ecosystem can be collected from the main flow of water to the top of the banks of the river and adjoining water bodies, the length of which from main riverine course vary from **50** to **100 m** based on water volume. Investigations were made at a monthly interval through three seasons of **2** years (2000–2002). All the macrophytic vegetations were grouped into three categories, **viz.**, aquatic, semiaquatic, and terrestrial. Coefficient of similarity among different categories, **viz**., aquatic, semiaquatic, and terrestrial plants, of different study sites were calculated using the Sorensen's similarity index.

$$\mathbf{SSI} = \frac{\mathbf{2C}}{\mathbf{A} + \mathbf{B}} \times \mathbf{100}$$

where

C = Common species from two sites
A = Total number of species from **1st** site
B = Total number of species from **2nd** site

Identification of plant species was made in consultation with standard literatures (Blasco 1977), monographs, and relevant floras.

9.7.2 Collection and Recording of Zooplankton and Other Aquatic Fauna

The zooplankton samples can be collected by filtering **100** l of water through the bolting nylon cloth (NO. -**25**, mesh size -**54** μ) and were preserved in **5%** buffered formalin (APHA 2000). The zooplankton species are identified following Edmondson (1959), Brooks (1959) Needham and Needham (1962), Michael and Sharma (1988), Battish (1992), Sharma (1993), Reddy (2001), and Sharma (2001). All the drawing and photographs of Rotifera are made using a phase contrast microscope (Model No. – **Carl Zeiss**, Germany – 912311). Mollusks, aquatic insects, and crustaceans are also collected from different collection sites manually by hand picking or by nets dragging over the vegetation. Other bottom-dwelling species are sorted out by using a metallic sieve having the mesh size of **0.5** mm and preserved in alcohol; sometimes buffered formaldehyde was used in the field. Careful visual observations are made during collection to find out the fauna. Identifications of collected specimen were done with the help of standard methods (Subba Rao 1989, Mitra and Kumar 1988) and subsequently confirmed by the scientists of Zoological Survey of India, Kolkata.

9.7.3 Diversity of Freshwater Ichthyofauna

Fishes are collected from various aquatic subsystems like rivers, streams, wetlands, etc. and directly from the fishermen as well as from the local markets, viz., Midnapore, Jhargram, Ghatal, Garbeta, Bankura, Arambag, Dehati, Khirai, Sonakonia, Kolaghat, and Khakurda, located at four districts of Southwest Bengal (**22–23.3**°**N; 86–88.3**°**E**) during different seasons like pre-monsoon (March–June), monsoon (July–October), and postmonsoon (November–February). Indigenous naming of different fishes is determined through focus group discussion (Mukherjee 1995). Collections are made randomly using bag nets, dragnets, cast nets, gill nets, seines, long line, different types of indigenous traps, etc. Fish species brought in the local markets from outside places were not taken into consideration. The specimens were preserved in **4%** buffered formalin immediately after collection and subsequently identified with the help of some standard literatures (Day 1878; Shaw and Shebbeare 1937; Jayaram 1999; Sen 1985; Beavan 1990; Talwar and Jhingran 1991; Menon 1999).

9.7.4 Fishing Technologies for Inland Water Bodies of Southwest Bengal

Four districts of Southwest Bengal are crisscrossed by several large rivers, their rivulets, canals, creeks, etc., which together with other adjoining wetlands constitute the inland water bodies. In the present study, six major rivers, viz., Subarnarekha, Dwarkeswar, Shilabati, Rupnarayan, Kansai, and Keleghai, and their adjoining water bodies were thoroughly investigated during different months, seasons, and years. Three seasons were pronounced in this area, **viz.**, pre-monsoon (less precipitation), monsoon (maximum precipitation), and postmonsoon. Collection and documentation of information relating to different fishing technologies were done through the participatory interaction with the stakeholders with a set of preformulated questionnaire in a village-level group meeting and by physical verification (Mukherjee 1995).

9.7.5 Participatory Methods: A Tool for Bio-assessment and Conservation

The participatory methods help in the involvement of local communities or stakeholders because it is they who do their own analysis through such methods, explain their findings and propose action on that basis. The method are both "**verbal**" and "**visual**" and involve the use of signs, symbols, objects, models, measures, etc. These methods are simple and handy and can be used by all.

9.7.5.1 Participatory Rural Appraisal (PRA) Techniques

A tool-based on people's perception, a "**basket of techniques**," adopted to interact with local communities, to understand them, and to learn from them, can be designated as **PRA** method.

This method facilitates better interaction with the local communities for indigenous knowledge-building exercise. This is also an alternative means of data collection and analysis. By means of this method, different kinds of data collection, identification, and mobilization of intended groups and provocation of their participations are possible, and furthermore, there are opening of various ways in which intended groups can participate in decision-making, project design, execution, and monitoring. **PRA** is a fruitful strategy where we can concentrate on people, their livelihoods, and their interrelationships with socioeconomic and ecological factors as it involves the participation of local community.

9.7.5.1.1 Questionnaire Survey

This type of survey involves investigation or enquiry about the people where they are treated as passive entities as they are not involved or they cannot influence the sense and direction of the ongoing enquiry. A picture-based questionnaire survey was conducted to evaluate the knowledge of the adjacent villagers regarding the declining of natural resources and the problem of developing eco-potentialities. Before conducting the interviews and taking necessary photographs, the verbal consents of the willing persons were taken. The questionnaire survey was conducted to explore two dimensions of people's cognizance through questionnaire to find out background information on socioeconomic status of the respondent (**viz.**, gender, age, and level of education of the respondents as enumerated in completed school years) in order to explore the effect of these variables on the knowledge of respondents (Kasina 2007) and questionnaire to attempt to extract the perception of respondents with respect to the possible causes of reduction of eco-potentialities. After taking the age profiles of the respondents in account, **30** willing participants of age 40 years and above were considered as the "**principal informants**" to categorize the commonly identified problems of bioresource declination.

Selected participatory rural appraisal techniques were carefully designed and applied to extract primary information relating to the conservation status of fishes. The techniques like (**a**) trend analysis, (**b**) fish magnitude value, (**c**) matrix ranking, and (**d**) rank-based quotient are being elaborated below.

9.7.5.1.2 Trend Analysis

The trend analysis is for depicting the nature of decline of a species over decades through applying participatory rural appraisal techniques. It has been done to analyze the nature of increasing or declining numbers of the target fish population over decades. In this analysis, the experience profiles of the stakeholders were also taken into consideration. In this method of trend analysis, the local people were interviewed to understand the trend of different variables from a historic perspective. The method helps in providing a background to any issue through trend analysis (Mukherjee 1997). For trend analysis, **75** respondents were put to an interactions in order to identify and assess the decadal decline of different fish species (**17**) in terms of time and visibility of the target species in the near and around surroundings. The scoring by villagers showed low amidst a declining trend, and population of indigenous fish species in the natural habitats (irrigation canal, tributaries, and rivers) reduced drastically from **1960** to **2000.**

9.7.5.1.3 Fish Magnitude Value (FMV)

It was calculated from a participatory approach where both the geographical and temporal dimensions were considered. **Fish magnitude value (FMV)** was designed and calculated from the vertical and horizontal logics. In this case, both the geographical distributions and temporal dimensions were taken into consideration. Calculation of the fish magnitude value was considered in conformity with the **IUCN** guidelines (IUCN 2001; Anon 2001).

The contention was that fish species had declined not only over a geographical space but also over the time. This is an innovative technique relying basically on the perceptual assessment by the fishermen of different age groups (**60** to **70** years old). This assessment is related to the decline of different fish species not only overtime but also over distribution, e.g., the fishermen assessed what have been the availability **vis-à-vis** biomass (**Kg**) of a fish species in a given decade (**60s**) in terms of scores designed by themselves and these score values were multiplied by the visibility range **vis-à-vis** the extent of their occurrence (**Km^2**), to help determine the status of that species in that decade. This type of calculation over decades would delineate by what percentage the decline has been occurring since the benchmark decade. To avoid the biases in the perceptual assessment made by an individual farmer, the total score value of a group was divided by the number of members of that very group to have an interpolated value in the form of a mean:

$$\textbf{Mean of FMV} = \frac{\textbf{Yield} \times \textbf{Area of Occupancy}}{\textbf{Number of respondents}}$$

9.7.5.1.4 Matrix Ranking

This unique method could be used to derive local perceptions and to quantify the perception so as to draw a logical inference on the reason and way of the superiority of one ecosystem over another. By applying this method, one can have an excellent estimation through a participatory mode of different attributes or values for different sites. Different attributes and criteria which were mentioned in a matrix scoring exercise were ranked according to their relative importance either on the basis of fixed scoring (say scoring out of ten). Perceptions of rural people could be revealed through an exercise in matrix scoring.

A number of causal factors were found to be instrumental for the declining of fish population from their natural habitats (irrigation canals, tributaries, wetlands, floodplains, and rivers) of Southwest Bengal. Group meetings with local fishermen community of some selected villages such as Kolaghat, Khakurda, Bankura, Arambag, Sonakonia, Dehati, Midnapore, Ghatal, Garbeta, and Khirai were organized to collect information related to factors responsible for declining of fishery resources.

Mostly the male members of the community assembled in the meeting place at a time. The set of criteria was discussed by the fishermen community. They were also requested to add to the list and to score on the set of criteria generated. Habitat destruction, nonrestricted nylon thread fishing gears, ichthyotoxic materials derived from local plants and also chemicals used for agriculture, fishing during breeding seasons, water pollution by wastes from human settlements and industries, fish diseases (epizootic ulcerative syndrome and others), excessive and nonjudicious use of water, human population explosion, occurrence of flood, introduction of exotic fish species, siltation, and fish bodies without being endowed with scales were found to be the major problems for the declining of fishery resources. To initiate the process of scoring by individuals, the criteria were written on piece of paper in vernacular (such criteria were read out loudly and understood by the participants, although many of them could not read or write) and arranged in a column on the ground. Each person was given a handful of stone chips (ten stone chips) and asked to score each criterion as much or as little as he wished to. It was free scoring as explained to the participants, where relative importance of a criterion would get indicated by putting more stone chips to more important ones and less stone chips to those which were relating less important.

9.7.5.1.5 Rank-Based Quotient (RBQ)

To calculate the interpolated values of different quality responses at both the vertical and horizontal dimensions is deliberately intercepted in this type of approach. At first, the individual choices for ranking against the relative position in the rank were calculated and then multiplied it by the rank values, and then the total values had been divided by the total number of members in the participatory groups. This approach is a unique concept to eradicate the flamboyancy of quality responses (Patra et al. 2005). To calculate rank-based quotient (**RBQ**) of each problem, the formula of Sabarathnam (1988); Sabarathnam and Sengottaiyan (1996) was used.

It was made to re-rank the identified causes in terms of their vertical and horizontal dimensions. Ranking was done with the help of **Rank-Based Quotient (RBQ)**. A focus group was formed. They were put to a discussion in identifying ten causal factors. It was made to rank the identified causes in terms of their vertical and horizontal dimensions:

$$\mathbf{RBQ} = \frac{\sum \mathbf{fi}(\mathbf{n} + \mathbf{1} - \mathbf{i})}{\mathbf{N} * \mathbf{n}} \times \mathbf{100}$$

where,

fi = frequency of respondents reporting the problem under ith rank,
I = rank of problems,
N = total number of respondents,
n = total number of problems.

In order to gather information about the factors responsible for a sharp decline in the eco-potentialities of wetlands over the decades, a meeting involving 60 local people was organized. After identifying some problems through participatory interactions, they were categorized, sorted, and screened. In these interactions, the number of participants was 20 for each focus group, and three such groups were created for necessary interactions to generate adequate data. Successful application of this type of participatory tool **(RBQ)** had already been practiced over decades to assess and document the nature and degree of decline of a score of selected bioresources.

9.7.5.1.6 Market Survey and Assessment of Fish Production

The data on average monthly landing of **17** siluroid fishes at the major fish markets of the study areas during **1997** to **2001** had been collected and presented. In this process, **eight** focus groups comprising of **five** fish retailers in each group having an age profile of above **50** years were taken into consideration from different landing centers. They were asked to present an account of fish landings at the respective markets in terms of **kg/month** for the last **5** years trickling from 1997.

9.7.5.1.7 Categorization of Fishes: A Prime Step for Conservation

The International Union for Conservation of Nature and Natural Resources **(IUCN)** categorizes the taxa in a given scheme depending upon the different criteria (**IUCN** 2001, Red List Categories and Criteria, **Version 3.1**). In the present work, the species was categorized specifically following the percentage of population size reduction and mean decline on market landing.

The percentage of population size reduction was calculated on the basis of **FMV** and was compared with the percentage given in the list. For critically endangered (**CR**), decline on FMV was **80%**, and mean decline on market landing was **60%**. For endangered (**EN**), decline on **FMV** was **70%**, and mean decline on market landing was **40%**.

For vulnerable (**VU**), decline on **FMV** was **50%**, and mean decline on market landing was **30%**. For near threatened (**NT**), decline on **FMV** was **<50%**, and mean decline on market landing was **15%**. The **IUCN** standardizes the percentage of population reduction over decades, which have been taken into consideration with the value of **FMV** (Patra et al. 2004; Patra et al. 2005; Mishra et al. 2009).

9.7.5.1.8 Causal Analysis: Understanding Cause and Effect

The perception of the outcomes through **PRA** method application cannot be done as that of the results of some laboratory-based research. The best way to disclose the benefits is an adequate discussion of the said outcome in the community.

Representation of a **PRA** process involves some diagrams, maps, ranking, flow-charts, etc. presenting and eliciting the local knowledge and experiences. The causes of decline or even extinction of bioresources in a given ecosystem can better be represented in a form of flow analysis which is known as causal diagram. The relationship between cause and effect of an event, process, or entity can be delineated by this method (Tables 9.1, 9.2, 9.3, 9.4 and 9.5).

Table 9.1 Some terms used to classify aquatic organisms by habitat

Habitat	Description
Benthic	On the bottom
Emergent	Emerging from the water
Endosymbiotic	Living within another organism
Epilithic	On rocks
Epigean	Above the ground
Epipelic	On mud
Epiphytic	On plants
Epipsammic	On sand
Hygropetric	In water on vertical rock surfaces
Hyporheic	In groundwater influenced by surface water
Lentic	In still water
Littoral	On lake shores, in shallow benthic zone of lakes
Lotic	In flowing water
Neustonic	On the surface of water
Pelagic	In open water
Periphytic (biofilm, Microphytobenthos)	Benthic, in a complex mixture including algae
Profundal	Deep in a lake
Symbiotic	Living very near or within another organism
Stygophilic	Actively use groundwater habitats for part of life cycle
Stygobitic	Specialized for life in groundwater
Torrenticole	Adapted to live in swiftly moving water

Table 9.2 Classification of interactions between two species (A and B)

Effect of A on B	Effect of B on A	Name of Interaction
Positive	Negative	Exploitation (includes predation and parasitism)
Negative	Negative	Competition
Positive	Positive	Mutualism
None	Positive	Commensalism
None	Negative	Amensalism
None	None	Neutralism

PRA teams consisting of people associated with the consumption, production, and maintenance of resource diversity and having of heterogeneous experiential profiles, social and economic backgrounds, etc. were structured to chalk out this type of analysis. The diversity created in the group composition was meant to identify, assess, and enumerate different causes, viz., biotic, abiotic, and social, from multiple realities (Tables 9.6, 9.7, 9.8, 9.9, 9.10, 9.11, 9.12, 9.13, 9.14, 9.15, 9.16, 9.17, 9.18, 9.19 and 9.20).

Table 9.3 Fish-stupefying plants used in Southern West Bengal, India

Sl no.	Scientific name	Local name	Family	Part(s) used	Habit
1	Bassia latifolia	Mahua	Sapotaceae	Oil cake of fruit	Tree
2	Casearia graveolens	Pimpri	Samydaceae	Bark	Small tree
3	Excoecaria agallocha	Gengwa	Euphorbiaceae	Latex	Small tree
4	Moringa oleifera	Sajne	Moringaceae	Root and bark paste	Tree
5	Nicotiana tabacum	Tamak	Solanaceae	Crushed plant	Herb
6	Polygonum hydropiper	Panmarich	Polygonaceae	Crushed plant	Shrub
7	Polygonum orientale	Panmarich	Polygonaceae	Crushed plant	Shrub
8	Pongamia pinnata	Karanj	Fabaceae	Oil cake	Tree
9	Sapindus mukorossi	Ritha	Sapindaceae	Fruit powder	Tree
10	Strychnos nux-vomica	Kuchila	Loganiaceae	Dried seed powder	Tree
11	Tamarindus indica	Tetul	Fabaceae	Dried seed powder	Tree
12	Tephrosia purpurea	Ban-nil	Fabaceae	Crushed plant	Herb
13	Tridax procumbens	Bisalyakarani	Asteraceae	Fresh leaf juice	Herb
14	Vangueria spinosa	Moyena kanta	Rubiaceae	Crushed fruit	Small tree

Table 9.4 A model of classifying streams by discharge patterns and relationship to aquatic communities

Drying frequency	Flood and discharge frequency/predictability	Stream type	Effect on biota
Often	Rare–frequent	Harsh intermittent	Strong
Low	Frequent	Intermittent flashy	Strong
Low	Infrequent	Intermittent runoff	Strong
Rare	Frequent unpredictable floods, low discharge predictability	Perennial flashy	Strong
Rare	Frequent predictable floods, low discharge predictability	Snow and Rain	Strong–intermediate
Rare	Infrequent floods, low discharge predictability	Perennial runoff	Strong–intermediate
Rare	Infrequent floods, high discharge predictability	Mesic groundwater	Weak
Rare	Infrequent predictable floods, high discharge predictability	Winter rain	Seasonally strong
Rare	Infrequent predictable floods, high discharge predictability	Snowmelt	Seasonally strong

Table 9.5 Characteristics of regional (top-down) vs local (bottom-up) strategies

	Regional (top-down)	Local (bottom-up)
Scale	Reach to network 1000 to 50,000 km river length 5000 to 500,000 km^2 (or greater)	Site to reach to small river basin 10 to 100 km river length 100 to 2000 km2
Management objectives	Assess geomorphic/ecological/identify/ chemical conditions of river reaches develop actions Target/prioritize actions	Diagnosis of trajectory, causes of change how it works Project design Pre-and post-project appraisal
Data sources	Satellite and airborne imagery LiDAR regional surveys	Historical maps, photos, surveys, accounts
	GIS national layers	Field measurements
	Network of stream gauges and SSC measures	Hydraulic modeling
	National-designed field campaigns (RHS)	In situ/ex situ experiments

9.7.5.1.9 Eco-assessment of Fishing Practices

Extensive survey has been made in different study sites of Southwest Bengal through different months and seasons in order to document the ongoing fishing technologies, which are being practiced. This has strong bearings on the conservation strategies to be undertaken for the protection of aquatic organisms. Different types of crafts, gears, and other traditional fishing technologies have already been documented. Due to the lack of restriction of mesh size, juveniles and many unwanted but ecologically important aquatic organisms are caught and destroyed leading to both economic and ecological losses.

Nylon threads used for making different gears also pose harmful effects during fishing operation as these damage different soft parts of both target and nontarget aquatic organisms. Application of the extracts of ichthyotoxic plants as a part of indigenous fishing technology should be reviewed with a holistic approach in order to save the steady state of environmental balance (Mishra et al. 2001, 2002, 2003).

9.7.5.1.10 Identification and Assessment of Anthropogenic and Environmental Stresses (Through RBQ Method)

A number of causal factors were found to be instrumental for the declining of fish population from their natural habitats (irrigation canals, tributaries, and rivers) of Southwest Bengal, India (Patra et al. 2005; Mishra et al. 2009).

Group meetings with local fishermen community of some selected villages, viz., Khakurda, Bankura, Arambag, Sonakonia, Dehati, Midnapore Sadar, and Khirai, were organized to collect information related to factors responsible for declining of fishery resources. Mostly the male members of the community (**Nos 30**) assembled in the meeting place at a time.

Table 9.6 Methodologies on environmental flows: global perspectives

Country	No. of EFMs (% of GT 207)	Total no. types (max 6)	No. of hydro (% of GT 61)	No. of hydraulic (% of GT 23)	No. of habitat sim (% of GT 16)	No. of holistic (% of GT 58)	No. of combin (% of GT 14)	No. of others (% of GT 35)
USA	77 (37%)	5	20 (33%)	19 (50%)	29 (50%)	–	8 (23%)	1 (7%)
Australia	37 (18%)	6	11 (18%)	1 (4%)	6 (10%)	11 (69%)	6 (17%)	2 (14%)
UK	23 (11%)	6	10 (16%)	1 (4%)	1 (2%)	1 (6%)	3 (9%)	7 (50%)
Canada	22 (11%)	4	9 (15%)	1 (4%)	10 (17%)	–		2 (14%)
South Africa	20 (10%)	5	6 (10%)	–	2 (3%)	5 (31%)	4 (11%)	3 (21%)
New Zealand	20 (10%)	5	8 (13%)	2 (9%)	6 (10%)	–	3 (9%)	1 (7%)
Spain	14 (7%)	4	8 (13%)		4 (7%)	–	1(3%)	1 (7%)
Italy	11 (5%)	5	4 (7%)	1 (4%)	1 (2%)	–	4 (11%)	1 (7%)
France	10 (5%)	3	3 (5%)		6 (10%)	–	1 (3%)	–
Portugal	10 (5%)	4	7 (11%)	1 (4%)	1 (2%)	–	1 (3%)	–

Numbers of environmental flow methodologies (**EFMs**) of different types and proportions of global totals for the 10 countries for which the highest total numbers of methodologies were recorded

Abbreviations: *GT* global total, *hydro* hydrological, *hydraulic* hydraulic rating, *habitat sim* habitat simulation, *combin* combination. A slash indicates on recorded application of the specific methodology type

Table 9.7 Identification of causal factors responsible for depletion of *Nandus nandus* (N = 30)

Sl no.	Causal factors	Ranking by farmers										RBQ values	Ranking of causal factors
		I	II	III	IV	V	VI	VII	VIII	IX	X		
1	Sluggish behavior	9		4				7		2		50.81	2
2	Attack of disease (epizootic ulcerative syndrome)	10			12	2						64.02	1
3	Use of nonrestricted nylon thread fishing gears		3		3	5			2			24.42	8
4	Occurrence of flood and siltation				10	7		7		2	3	43.88	3
5	Fishing during breeding seasons			5		3		6		7		29.7	7
6	Ichthyotoxic materials (plants/ chemicals)	1		1		7	6		3	5		30.75	6
7	Pesticides used for agriculture			5	3			6	5	7	1	37.95	5
8	Excessive and nonjudicious use of water	1		1			6		5	5		21.51	9
9	Introduction of exotic fish species			2		4		4	1		2	17.49	10
10	Habitat destruction			11	2				5			38.61	4

The set of criteria was discussed by the fishermen community who were also requested to add to the list and to score on the set of criteria generated. Habitat destruction, usage of nonrestricted nylon thread fishing gears, application of ichthyotoxic materials (plants and chemicals), fishing during breeding seasons, water pollution, siltation, multifarious water use, human population pressure, sluggish behavior of some fish, fish diseases (epizootic ulcerative syndrome and others), and introduction of exotic fish species are the major problems for the declining of fishery resources. To initiate the process of scoring by individuals, the criteria were written on piece of paper in vernacular (such criteria were read out loudly and understood by the participants, although many of them could not read or write) and arranged in a column on the ground.

Table 9.8 Identification of causal factors responsible for depletion of *Puntius sarana* (N = 30)

Sl no.	Causal factors	Ranking by farmers										RBQ values	Ranking of causal factors
		I	II	III	IV	V	VI	VII	VIII	IX	X		
1	Habitat destruction	**10**			**12**			**7**				**69.96**	**1**
2	Water pollution by wastes from human settlements			**9**			**6**	**4**	**5**		**2**	**41.97**	**3**
3	Use of nonrestricted nylon thread fishing gears	**1**		**1**		**2**	**6**		**3**	**5**		**25.47**	**8**
4	Introduction of exotic fish species	**3**			**4**			**2**	**8**			**29.7**	**5**
5	Fishing during breeding seasons				**10**			**7**		**2**	**3**	**34.64**	**4**
6	Ichthyotoxic materials (plants/ chemicals)	**1**		**1**						**5**		**9.24**	**10**
7	Pesticides used for agriculture	**9**	**4**	**4**				**4**				**57.42**	**2**
8	Attack of disease (epizootic ulcerative syndrome)		**5**			**6**			**7**			**27.12**	**6**
9	Sluggish behavior			**1**	**2**	**5**			**5**			**22.11**	**9**
10	Occurrence of flood and siltation		**5**				**6**		**7**	**1**		**26.07**	**7**

Each person was given a handful of stone chips (**ten stone chips**) and asked to score each criterion as much or as little as he wished to. It was free scoring as explained to the participants, where relative importance of a criterion would get indicated by putting more stone chips to more important ones and less stone chips to those which were relating less important. Ranking were done with the help of **rank-based quotient** (**RBQ**). A focus group was formed.

They were put to a discussion in identifying ten causal factors and extract their relative value on the declining trend of fish population in general and also five selected species (two critically endangered, **viz.**, *Nandus nandus* and *Puntius sarana*, and three endangered, viz., *Ompok pabo*, *Ailia coila*, and *Eutropiichthys vacha*) in particular.

Table 9.9 Identification of causal factors responsible for depletion of *Eutropiichthys vacha* (N = 30)

SL no.	Causal factors	Ranking by farmers										RBQ values	Ranking of causal factors
		I	II	III	IV	V	VI	VII	VIII	IX	X		
1	Habitat destruction	**9**	**4**	**4**				**7**	**1**			62.37	2
2	Water pollution by wastes from human settlements			**5**				**6**		**7**	**1**	26.07	7
3	Use of nonrestricted nylon thread fishing gears	**1**		**1**		**5**			**5**	**5**		22.11	8
4	Introduction of exotic fish species			**5**	**3**			**6**		**7**		32.67	6
5	Fishing during breeding seasons		**4**	**11**	**2**				**5**			50.49	3
6	Ichthyotoxic materials (plants/ chemicals)				**10**			**7**		**2**	**3**	34.64	5
7	Pesticides used for agriculture				**12**	**2**		**4**				36.96	4
8	Excessive and nonjudicious use of water	**1**		**1**			**6**		**3**	**5**		21.51	9
9	Sluggish behavior		**3**						**2**			10.89	10
10	Occurrence of flood and siltation	**15**		**2**			**6**	**4**			**2**	70.02	1

Then, they were also made to assess the extent of the impact area and the intensity of the problems so as to finally attain the village magnitude value, which were subsequently ranked to provide a holistic idea of the problem.

9.7.5.1.11 Decade-Wise Trend Analysis of Selected Fish Species

In this method of trend analysis, the local people were interviewed to understand the trend of different variables from a historic perspective. The method helps in providing a background to any issue through trend analysis (Mukherjee 1997).

Table 9.10 Identification of causal factors responsible for the depletion of *Ompok pabo* (N = 30)

SL no.	Causal factors	Ranking by farmers										RBQ values	Ranking of causal factors
		I	II	III	IV	V	VI	VII	VIII	IX	X		
1	Habitat destruction	**9**	**4**	**4**				**7**				61.38	1
2	Water pollution by wastes from human settlements	**1**		**1**			**6**		**3**	**5**		21.51	7
3	Use of nonrestricted nylon thread fishing gears	**1**		**1**		**5**	**6**		**5**	**5**		31.41	6
4	Introduction of exotic fish species							**6**		**7**		12.54	8
5	Fishing during breeding seasons			**11**	**2**	**5**			**5**			48.51	3
6	Ichthyotoxic materials (plants/ chemicals)			**5**	**3**			**6**		**7**	**1**	33	5
7	Pesticides used for agriculture	**15**		**2**					**1**			55.77	2
8	Attack of disease (epizootic ulcerative syndrome)			**2**				**4**	**1**		**2**	12.21	9
9	Sluggish behavior		**3**						**2**			10.89	10
10	Occurrence of flood and siltation				**10**	**2**		**7**		**2**	**3**	38.6	4

The scoring by villagers showed low amidst a declining trend, and population of indigenous fish species in the natural habitats (irrigation canal, tributaries, and rivers) reduced drastically between **1960** and **2000**. About **175** fishermen participated to deliver their knowledge about the decade-wise declining trend of **27** selected fish species of Southwest Bengal. Although a total of **103** freshwater fishes have been recorded from different water bodies of Southwest Bengal, India, to generate information relating to the quantum of production **vis-à-vis** catch from natural water bodies, a number of markets (**6**) located near the harvesting sites were selected for continuous market survey. A total of **52** species of fishes were found to constitute bulk of fish resources of those markets.

Table 9.11 Identification of causal factors responsible for depletion of *Ailia coila* (N = 30)

SL no.	Causal factors	Ranking by farmers										RBQ values	Ranking of causal factors
		I	II	III	IV	V	VI	VII	VIII	IX	X		
1	Habitat destruction	**10**			**12**			**4**				**66**	**1**
2	Water pollution by wastes from human settlements			**9**		**2**				**2**		**29.03**	**6**
3	Use of nonrestricted nylon thread fishing	**1**		**1**			**6**		**5**	**5**		**21.51**	**8**
4	Introduction of exotic fish species gears		**4**	**4**				**7**				**31.68**	**5**
5	Fishing during breeding seasons	**1**		**1**		**2**	**6**		**3**	**5**		**25.47**	**7**
6	Ichthyotoxic materials (plants/ chemicals)				**10**			**7**		**2**	**3**	**34.64**	**4**
7	Pesticides used for agriculture	**15**		**2**				**4**	**1**		**2**	**61.71**	**2**
8	Excessive and nonjudicious use of water							**6**		**7**		**12.54**	**9**
9	Sluggish behavior		**3**						**2**			**10.89**	**10**
10	Occurrence of flood and siltation		**3**	**11**	**2**				**5**			**47.52**	**3**

Out of these **52** species of fishes, **27** species were picked up based on their present availability against overexploitation coupled with environmental degradation and also to study their conservation categories. It was found from the information based on the decline of **FMV** after **2000**, the population of *Nandus nandus* experienced maximum decline (**86.15%**) followed by Puntius sarana (**83.78%**) which suffered an abrupt decline between **1960** and **2000**, and the decline of **FMV** after last decay in other species would have been as follows: *Rita rita* **62.82%**, *Batasio batasio* **41.76%**, *Lepidocephalus guntea* **48.13%**, *Mystus cavasius* **70.48%**, *Mystus vittatus* **63.20%**, *Ompok pabda* **74.64%**, *Ompok pabo* **79.46%**, *Wallago attu* **61.07%**, *Ailia coila* **76.13%**, Clupisoma garua **63.65%**, *Eutropiichthys vacha* **78.00%**, *Pangasius pangasius* **43.88%**, *Bagarius bagarius* **33.94%**, *Clarias batrachus* **41.27%**, *Arius gagora* **47.65%**, *Heteropneustes fossilis* **32.23%**, *Notopterus nopterus* **60.55%**,

Table 9.12 Segregated figure on decadal fish magnitude value (FMV) for 27 selected fish species

SL. no.	Local name	Scientific name	1960	1970	1980	1990	2000	Mean	SD
1	Rita	*Rita rita*	236.50	203.70	169.06	101.46	37.72	149.69	80.14
2	Batasi, tengra	*B. batasio*	196.30	180.70	90.00	35.20	20.50	104.54	81.09
3	Gento	*L. guntia*	183.80	163.20	123.50	93.50	48.50	122.50	54.16
4	Pat tengra	*M. cavasius*	296.20	262.33	214.50	61.66	18.20	170.58	123.70
5	Dorakata tengra	*M. vittatus*	232.13	200.70	175.60	107.60	39.60	151.13	77.38
6	Nayna	*N. nandus*	156.00	132.50	78.60	32.50	4.50	80.82	64.20
7	Swarna punti	*P. sarana*	148.50	120.60	58.50	18.50	3.00	69.82	63.24
8	Pabda	*O. pabda*	191.87	163.50	128.50	48.50	12.30	108.93	76.21
9	Pabda	*O. pabo*	266.80	253.50	220.70	66.20	13.60	164.16	116.17
10	Boal	*W. attu*	190.50	170.00	110.00	65.50	25.50	112.30	69.24
11	Banspata	*A. coila*	174.30	112.50	89.60	77.50	18.50	94.48	56.53
12	Fultusi	*C. garua*	158.50	123.40	109.60	89.40	32.50	102.68	46.62
13	Bacha	*E. vacha*	185.70	157.80	122.50	93.20	20.50	115.94	63.81
14	Pangas	*P. pangasius*	259.80	231.70	208.40	119.20	66.90	177.20	81.08
15	Baghar	*B. bagarius*	87.20	68.80	54.30	38.60	25.50	54.88	24.33
16	Magur	*C. batrachus*	254.30	224.50	176.50	104.20	61.20	164.14	80.80
17	Goar aar	*A. gagora*	313.33	282.07	278.09	253.09	132.50	251.82	70.05
18	Singi	*H. fossilis*	287.53	253.40	230.00	166.00	112.50	209.89	70.24
19	Pholui	*N. nopterus*	287.80	266.66	225.30	86.05	33.95	179.95	113.29
20	Shol	*C. striatus*	211.12	174.15	154.50	112.20	71.50	144.69	54.29
21	Mourola	*A. mola*	279.60	252.30	213.90	111.50	59.80	183.42	94.05
22	Koi	*A. testudineus*	257.50	226.13	188.70	90.80	35.16	159.66	93.64
23	Lata	*C. punctatus*	224.20	196.16	152.50	64.13	27.66	132.93	84.45
24	Pangkal	*M. pancalus*	217.13	182.00	151.40	84.60	47.50	136.53	69.66
25	Arr tengra	*A. seenghala*	310.50	250.40	215.60	150.00	89.20	203.14	86.20
26	Cheng	*C. orientalis*	255.10	225.14	190.86	97.20	49.00	163.46	87.24
27	Ilish	*T. illisa*	254.30	224.50	190.00	83.06	44.60	159.29	91.09

Table 9.13 Quantum of production of fishes during the year 2000–2002 (from market survey, expressed in Kg/year) in main landing centers of six rivers and their associated water bodies

SL. no.	Name of fishes	Common name	Midnapore (Kansai)		Dehati (Kelegha)		Rohini (Subarnarekha)		Dhadika (Shilabati)		Kolaghat (Rupnarayan)		Bankura (Dwarkeswar)	
			2000–2001	2001–2002	2000–2001	2001–2002	2000–2001	2001–2002	2000–2001	2001–2002	2000–2001	2001–2002	2000–2001	2001–2002
1	*Labeo rohita*	Rui	225	237	212	201	290	302	170	171.5	–	–	165	167
2	*Labeo calbasu*	Kalbasu	125	119	95	88.5	131	128	102	98.5	–	–	90	88
3	*Labeo bata*	Bata	320	298	75	79	250	248	82	81.5	–	–	79	76
4	*Labeo boga*	Bangan	173	174	50.5	49.5	167	177	75	16	–	–	78	76.5
5	*Cirrhinus mrigala*	Mrigal	92	72	75	78.5	103	108.5	82	81	–	–	84.75	81.5
6	*Catla catla*	Catla	252	267	115	98	305	288.5	117	112	–	–	105	102
7	*Puntius sophore*	Puthi	280.6	264	202.7	160	288	267	235.8	237.5	–	–	230	219.5
8	*Puntius ticto*	Puthi	175.8	157	55.7	61	180.8	165.5	180.7	123	–	–	185.75	181.5
9	Puntius sarana	Swarna-puti	–	–	2	1.5	1	–	–	–	–	–	–	–
10	*Hypophthalmichthys molitrix*	Silver carp	200.7	210.5	172.4	189.5	310.75	297	173.8	177	–	–	153.75	155
11	Cyprinus carpio	Cyprinus	55	58	35	54	62	64	42	41.5	–	–	39	37.5
12	*Ctenopharyngodon idella*	Grass carp	105	111	90.5	110	110	117.5	100.8	88.5	–	–	98	97.5
13	*Mystus bleekeri*	Golsha tengra	405	387	290	287	432	429	328	281	–	–	281	277
14	*Mystus cavasius*	Pat tengra	190	178.5	35	32.5	180	167.5	105.5	97	–	–	125	119
15	*Mystus gulio*	Nuna tengra	54	47	61.5	52.8	35	28.5	54	51.5	–	–	–	–
16	*Mystus vittatus*	Dorakata Tengra	69.5	62	71.5	69	65.5	49.2	62	58.5	–	–	–	–
17	Aorichthys aor	Arr	215	210.5	115	113.5	70	71	175	168	76.5	78	45	43

(continued)

Table 9.13 (continued)

SL. no.	Name of fishes	Common name	Midnapore (Kansai)		Dehati (Kelegha)		Rohini (Subarnarekha)		Dhadika (Shilabati)		Kolaghat (Rupnarayan)		Bankura (Dwarkeswar)	
			2000–2001	2001–2002	2000–2001	2001–2002	2000–2001	2001–2002	2000–2001	2001–2002	2000–2001	2001–2002	2000–2001	2001–2002
18	*Aorichthys seenghala*	Arr tengra	405	378.5	–	–	202	197.5	–	–	129.5	126.5	–	–
19	*Ompok bimaculatus*	Puffta	310	303.5	–	–	180	173	170	161	–	–	–	–
20	*Ompok pabda*	Pabda	78	71	32	27	19	17.5	14	12.5	–	–	–	–
21	*Ompok pabo*	Pabo	51.5	45.5	47	39.5	53	49	37	33.5	–	–	–	–
22	*Wallago attu*	Boal	303	276	226.5	219.8	398	384	189	188	185	183	175	173.5
23	*Ailia coila*	Kajri	155	141	–	–	75	69	–	–	–	–	–	–
24	*Clarias batrachus*	Magur	50.80	42.5	62	58	55	52.5	40	39	–	–	42	41
25	*Heteropneustes fossilis*	Singi	60.3	56.5	40	39	65	61	51	43	–	–	52	52
26	*Clupisoma garua*	Fultusi	295	263	–	–	75	72	–	–	–	–	–	–
27	*Pangasius pangasius*	Pangas	–	–	–	–	85	80	–	–	320	314	–	–
28	*Rita rita*	Rita	103.5	96.5	–	–	10.5	9	14.5	13	–	–	0.5	–
29	Batasio batasio	Batasi tengra	62	57.5	–	–	51	49	37	35.5	–	–	–	–
30	*Channa striatus*	Shol	85	76	51.5	49	86.8	78.5	58	57	–	–	52	48.2
31	*Channa punctatus*	Lata	322	312.5	180	177	355	312	175	165	–	–	245	240
32	*Channa orientalis*	Cheng	65	57	53	45.5	85	84	54.5	535	–	–	82	80
33	*Notopterus chitala*	Chital	210	199	77	71	192	191	69.5	64	–	–	73.5	71
34	*Notopterus notopterus*	Pholui	300.7	267	185	166	370	368	196	191.5	–	–	193	185.5
35	*Gudusia chapra*	Khira	–	–	–	–	–	–	–	–	1900	–	–	–
36	*Tenualosa ilisha*	Ilish	–	–	–	–	35	33.5	–	–	2800	–	–	–

37	*Securicula gora*	Ghora chela	42	37	–	–	–	–	–	–	–	–	–	–
38	*Chela cachius*	Chela	175	147.5	95	90.5	185	166	173	168.5	–	–	170	168
39	*Polynemus paradiseus*	Tapsya	–	–	–	–	–	–	–	–	2200	–	–	–
40	*Nandus nandus*	Nayna	–	–	0.5	–	1.5	1	–	–	–	–	–	–
41	*Bagarius bagarius*	Baghar	–	–	2	2	0.5	–	–	–	–	–	–	–
42	*Eutropiichthys vacha*	Bacha	25.5	24	5	4.5	10	9.5	21.5	19	–	–	–	–
43	*Arius gagora*	Goar arr	14	13.5	8	8	7	6.5	12	9.5	–	–	–	–
44	*Esomus danricus*	Jongia	280	276	197	190	292	291	283.75	280	-	–	203.3	200
45	*Amblypharyngodon mola*	Mourola	302	297	275	276	312.75	310	265.7	263	–	–	225.7	212
46	*Xenentodon cancila*	Kankley	307	289	150	148	285.7	283	179.3	172	–	–	182	181.5
47	*Glossogobius giuris*	Bele	103	78	75	76	119.8	117	103.7	98	–	–	97	96
48	*Anabas testudineus*	Koi	112	81	52	68	170	171	62	61	–	–	67	65.5
49	*Macrognathus pancalus*	Pangkal	175	167	90	91	187	195.5	93	89	–	–	97	96
50	*Setipinna* spp.	Paasa	–	–	–	–	–	–	–	–	1100	1078	–	–
51	*Lates calcarifer*	Vetki	378	372.5	412	410.5	64	62.5	105	104	–	–	–	–
52	*Anguilla bengalensis*	Ban	137	133	76	74.8	58.5	57	108	109	54.5	53	–	–
53	Prawns and shrimps	Chingri or kucho chingri	675	689.5	2000	1978	975	1021	670	654.5	1450	1377.2	630	541
	Total		8519.9	8100.5	6145.3	6034.4	8042.1	7879.7	5268.05	5449.5	10215.5	3209.7	4346.25	4172.2

Table 9.14 Decade-wise trend analysis of selected 27 freshwater fishes of South West Bengal

SL. no.	Local name	Scientific name	1960	1970	Decline %	1980	Decline %	1990	Decline %	2000	Decline %	Mean decline	Category
1	Rita	*Rita rita*	236.50	203.70	13.87	169.06	17.01	101.46	39.99	37.72	62.82	33.42	VU
2	Batasi tengra	*B. batasio*	196.30	180.70	7.95	90.00	50.19	35.20	60.89	20.50	41.76	40.20	NT
3	Gento	L. guntia	183.80	163.20	11.21	123.50	24.33	93.50	24.29	48.50	48.13	26.99	NT
4	Pat tengra	*M. cavasius*	296.20	262.33	11.43	214.50	18.23	61.66	71.25	18.20	70.48	42.85	VU
5	Dorakata tengra	*M. vittatus*	232.13	200.70	13.54	175.60	12.51	107.60	38.72	39.60	63.20	31.99	VU
6	Nayna	*N. nandus*	156.00	132.50	15.06	78.60	40.68	32.50	58.65	4.50	86.15	50.14	CE
7	Swarna Punti	*P. sarana*	148.50	120.60	18.79	58.50	51.49	18.50	68.38	3.00	83.78	55.61	CE
8	Pabda	*O. pabda*	191.87	163.50	14.79	128.50	21.41	48.50	62.26	12.30	74.64	43.27	VU
9	Pabda	*O. pabo*	266.80	253.50	4.99	220.70	12.94	66.20	70.00	13.60	79.46	41.85	EN
10	Boal	*W. attu*	190.50	170.00	10.76	110.00	35.29	65.50	40.45	25.50	61.07	36.89	VU
11	Banspata	*A. coila*	174.30	112.50	35.46	89.60	20.36	77.50	13.50	18.50	76.13	36.36	EN
12	Fultusi	C. garua	158.50	123.40	22.15	109.60	11.18	89.40	18.43	32.50	63.65	28.85	VU
13	Bacha	*E. vacha*	185.70	157.80	15.02	122.50	22.37	93.20	23.92	20.50	78.00	34.83	EN
14	Pangas	*P. pangasius*	259.80	231.70	10.82	208.40	10.06	119.20	42.80	66.90	43.88	26.89	NT
15	Baghar	*B. bagarius*	87.20	68.80	21.10	54.30	21.08	38.60	28.91	25.50	33.94	26.26	LC
16	Magur	*C. batrachus*	254.30	224.50	11.72	176.50	21.38	104.20	40.96	61.20	41.27	28.83	NT
17	Goar aar	*A. gagora*	313.33	282.07	9.98	278.09	1.41	253.09	8.99	132.50	47.65	17.01	NT
18	Singi	*H. fossilis*	287.53	253.40	11.87	230.00	9.23	166.00	27.83	112.50	32.23	20.29	LC
19	Pholui	*N. nopterus*	287.80	266.66	7.35	225.30	15.51	86.05	61.81	33.95	60.55	36.30	VU
20	Shol	*C. striatus*	211.12	174.15	17.51	154.50	11.28	112.20	27.38	71.50	36.27	23.11	LC
21	Mourola	*A. mola*	279.60	252.30	9.76	213.90	15.22	111.50	47.87	59.80	46.37	29.81	NT
22	Koi	*A. testudineus*	257.50	226.13	12.18	188.70	16.55	90.80	51.88	35.16	61.28	35.47	VU

23	Lata	*C. punctatus*	224.20	196.16	12.51	152.50	22.26	64.13	57.95	27.66	56.87	37.40	VU
24	Pangkal	*M. pancalus*	217.13	182.00	16.18	151.40	16.81	84.60	44.12	47.50	43.85	30.24	NT
25	Arr tengra	*A. seenghala*	310.50	250.40	19.36	215.60	13.90	150.00	30.43	89.20	40.53	26.05	NT
26	Cheng	*C. orientalis*	255.10	225.14	11.74	190.86	15.23	97.20	49.07	49.00	49.59	31.41	NT
27	Ilish	*T. illisa*	254.30	224.50	11.72	190.00	15.37	83.06	56.28	44.60	46.30	32.42	NT

FMV decline after 2000 in case of critically endangered (**CE**) **= > 80 [2** species]; endangered (**EN**) **= 75–80** [**3** species]; vulnerable (**VU**) **= 50–75** [**9** species]; near threatened (**NT**) **=** 40–50, [**10 species**]; least concern (LC) **= <40** [**3 species**]

Table 9.15 Identification of causal factors responsible for depletion of fishes (N = 30)

SL. no.	Causal factors	Ranking by farmers										RBQ Values	Re-ranking of causal factors
		I	II	III	IV	V	VI	VII	VIII	IX	X		
1	Ichthyotoxic materials (plants/ chemicals)		**5**						**1**			**16**	**VI**
2	Habitat destruction	**16**		**3**								**61.33**	**I**
3	Fishing during breeding seasons	**10**						**1**				**34.63**	**II**
4	Introduction of exotic fish species			**5**							**1**	**13.63**	**X**
5.	Occurrence of flood and siltation.		**9**									**27**	**IV**
6	Water pollution by wastes from human settlements				**2**			**1**		**1**		**6.65**	**IX**
7	Pesticides used for agriculture	**4**		**6**	**4**							**38.6**	**III**
8	Excessive and nonjudicious use of water		**7**				**2**					**24.3**	**V**
9	Use of nonrestricted nylon thread fishing gears		**6**									**18**	**VII**
10	Human population explosion		**1**		**4**							**12.3**	**VIII**

RBQ = $\boldsymbol{\sum^{n} fi\,(n + 1 - i)/Nn \times 100}$
where *N* total number of fishermen or key informants, i.e., **30**; ***n*** number of ranks, ***i*** rank position; and *fi* frequency of **i**

Channa striatus **36.27%**, *Amblypharyngodon mola* **46.37%**, *Anabas testudineus* **61.28%**, *Channa punctatus* **56.87%**, *Macrognathus pancalus* **43.85%**, *Aorichthys seenghala* **40.53%**, *Channa orientalis* **49.59%**, and *Tenualosa illisa* **46.30%**. Decadal mean of **FMV** of different other species would have been as follows*: Rita rita* **149.69**, *Batasio batasio* **104.54**, *Lepidocephalus guntia* **122.50**, *Mystus cavasius* **170.58**, *Mystus vittatus* **151.13**, *Nandus nandus* **69.82**, *Puntius sarana*

Table 9.16 Quantum of production of fishes during the year 2000–2002 (from market survey, expressed in Kg/year) in main landing centers of six rivers and their associated water bodies

SL. no.	Name of fishes	Common name	Midnapore (Kansai)		Dehati (Keleghai)		Rohini (Subarnarekha)		Dhadika (Shilabati)		Kolaghat (Rupnarayan)		Bankura (Dwarkeswar)	
			2000–2001	2001–2002	2000–2001	2001–2002	2000–2001	2001–2002	2000–2001	2001–2002	2000–2001	2001–2002	2000–2001	2001–2002
1	*Labeo rohita*	Rui	225	237	212	201	290	302	170	171.5	–	–	165	167
2	*Labeo calbasu*	Kalbasu	125	119	95	88.5	131	128	102	98.5	–	–	90	88
3	*Labeo bata*	Bata	320	298	75	79	250	248	82	81.5	–	–	79	76
4	*Labeo boga*	Bangan	173	174	50.5	49.5	167	177	75	16	–	–	78	76.5
5	*Cirrhinus mrigala*	Mrigal	92	72	75	78.5	103	108.5	82	81	–	–	84.75	81.5
6	*Catla catla*	Catla	252	267	115	98	305	288.5	117	112	–	–	105	102
7	*Puntius sophore*	Puthi	280.6	264	202.7	160	288	267	235.8	237.5	–	–	230	219.5
8	*Puntius ticto*	Puthi	175.8	157	55.7	61	180.8	165.5	180.7	123	–	–	185.75	181.5
9	*Puntius sarana*	Swarna-puti	–	–	2	1.5	1	–	–	–	–	–	–	–
10	*Hypophthalmichthys molitrix*	Silver carp	200.7	210.5	172.4	189.5	310.75	297	173.8	177	–	–	153.75	155
11	*Cyprinus carpio*	Cyprinus	55	58	35	54	62	64	42	41.5	–	–	39	37.5
12	*Ctenopharyngodon idella*	Grass carp	105	111	90.5	110	110	117.5	100.8	88.5	–	–	98	97.5
13	*Mystus bleekeri*	Golsha tengra	405	387	290	287	432	429	328	281	–	–	281	277
14	*Mystus cavasius*	Pat tengra	190	178.5	35	32.5	180	167.5	105.5	97	–	–	125	119
15	*Mystus gulio*	Nuna tengra	54	47	61.5	52.8	35	28.5	54	51.5	–	–	–	–
16	*Mystus vittatus*	Dorakata Tengra	69.5	62	71.5	69	65.5	49.2	62	58.5	–	–	–	–

(continued)

Table 9.16 (continued)

SL. no.	Name of fishes	Common name	Midnapore (Kansai) 2000–2001	Midnapore (Kansai) 2001–2002	Dehati (Keleghai) 2000–2001	Dehati (Keleghai) 2001–2002	Rohini (Subarnarekha) 2000–2001	Rohini (Subarnarekha) 2001–2002	Dhadika (Shilabati) 2000–2001	Dhadika (Shilabati) 2001–2002	Kolaghat (Rupnarayan) 2000–2001	Kolaghat (Rupnarayan) 2001–2002	Bankura (Dwarkeswar) 2000–2001	Bankura (Dwarkeswar) 2001–2002
17	Aorichthys aor	Arr	215	210.5	115	113.5	70	71	175	168	76.5	78	45	43
18	*Aorichthys seenghala*	Arr tengra	405	378.5	–	–	202	197.5	–	–	129.5	126.5	–	–
19	*Ompok bimaculatus*	Puffta	310	303.5	–	–	180	173	170	161	–	–	–	–
20	*Ompok pabda*	Pabda	78	71	32	27	19	17.5	14	12.5	–	–	–	–
21	*Ompok pabo*	Pabo	51.5	45.5	47	39.5	53	49	37	33.5	–	–	–	–

Table 9.17 Identification of causal factors responsible for depletion of fishes (**N** = **30**)

SL. No.	Causal factors	Ranking by farmers										RBQ Values	Re-ranking of causal factors
		I	II	III	IV	V	VI	VII	VIII	IX	X		
1	Ichthyotoxic materials (plants/ chemicals)		**5**						**1**			**16**	**VI**
2	Habitat destruction	**16**		**3**								**61.33**	**I**
3	Fishing during breeding seasons	**10**						**1**				**34.63**	**II**
4	Introduction of exotic fish species			**5**							**1**	**13.63**	**X**
5	Occurrence of flood and siltation		**9**									**27**	**IV**
6	Water pollution by wastes from human settlements				**2**			**1**		**1**		**6.65**	**IX**
7	Pesticides used for agriculture	**4**		**6**	**4**							**38.6**	**III**
8	Excessive and nonjudicious use of water		**7**				**2**					**24.3**	**V**
9	Use of nonrestricted nylon thread fishing gears		**6**									**18**	**VII**
10	Human population explosion		**1**		**4**							**12.3**	**VIII**

RBQ = $\sum^{n}$ **fi (n + 1−i)/Nn × 100**
where *N* total number of fishermen or key informants, i.e., 30, *n* number of ranks, *i* rank position, and *fi* frequency of i

69.82, *Ompok pabda* **108.93**, *Ompok pabo* **164.16**, *Wallago attu* **112.30**, *Ailia coila* **94.48**, *Clupisoma garua* **102.68**, *Eutropiichthys vacha* **115.94**, *Pangasius pangasius* **177.20**, Bagarius bagarius **54.88**, Clarias batrachus **164.14**, *Arius gagora* **251.82**, *Heteropneustes fossilis* **209.89**, *Notopterus nopterus* **179.95**, *Channa striatus* **144.69**, *Amblypharyngodon mola* **183.42**, *Anabas testudineus* **159.66**, *Channa punctatus* **132.93**, *Macrognathus pancalus* **136.53**, *Aorichthys seenghala* **203.14**, *Channa orientalis* **163.46**, and *Tenualosa illisa* **159.29**.

Table 9.18 Identification of causal factors responsible for depletion of *Eutropiichthys vacha* (N = 30)

SL no.	Causal factors	Ranking by farmers										RBQ values	Ranking of causal factors
		I	II	III	IV	V	VI	VII	VIII	IX	X		
1	Habitat destruction	**9**	**4**	**4**				**7**	**1**			62.37	2
2	Water pollution by wastes from human settlements			**5**				**6**		**7**	**1**	26.07	7
3	Use of nonrestricted nylon thread fishing gears	**1**		**1**		**5**			**5**	**5**		22.11	8
4	Introduction of exotic fish species			**5**	**3**			**6**		**7**		32.67	6
5	Fishing during breeding seasons		**4**	**11**	**2**				**5**			50.49	3
6	Ichthyotoxic materials (plants/ chemicals)				**10**			**7**		**2**	**3**	34.64	5
7	Pesticides used for agriculture				**12**	**2**		**4**				36.96	4
8	Excessive and nonjudicious use of water	**1**		**1**			**6**		**3**	**5**		21.51	9
9	Sluggish behavior		**3**						**2**			10.89	10
10	Occurrence of flood and siltation	**15**		**2**			**6**	**4**			**2**	70.02	1

For trend analysis, **175** respondents were put to an interactions in order to identify and assess the decadal decline of different fish species (**27**) in terms of time and visibility of the target species in the near and around surroundings. Decade-wise trend analysis of **27** selected freshwater fishes of Southwest Bengal generated mean decline value based on which the following conservation categories have been determined, taking into consideration the guidelines put forward by the **IUCN** (2001) regarding the different conservation categories. In this work five different conservation categories have been made based on the following criteria (Patra et al. 2005): **critically endangered** (**CE**), the decline of **FMV** after last decay should be **>80**; endangered (**EN**), the decline of **FMV** after last decay should be **75–80**; vulnerable (**VU**), the decline of **FMV** after last decay should be **50–75**; near

Table 9.19 Identification of causal factors responsible for depletion of *Ompok pabo* (**N** = **30**)

SL no.	Causal factors	Ranking by farmers										RBQ values	Ranking of causal factors
		I	II	III	IV	V	VI	VII	VIII	IX	X		
1	Habitat destruction	**9**	**4**	**4**				**7**				61.38	1
2	Water pollution by wastes from human settlements	**1**		**1**			**6**		**3**	**5**		21.51	7
3	Use of nonrestricted nylon thread fishing gears	**1**		**1**		**5**	**6**		**5**	**5**		31.41	6
4	Introduction of exotic fish species							**6**		**7**		12.54	8
5	Fishing during breeding seasons			**11**	**2**	**5**			**5**			48.51	3
6	Ichthyotoxic materials (plants/chemicals)			**5**	**3**			**6**		**7**	**1**	33	5
7	Pesticides used for agriculture	**15**		**2**					**1**			55.77	2
8	Attack of disease (epizootic ulcerative syndrome)			**2**				**4**	**1**		**2**	12.21	9
9	Sluggish behavior		**3**						**2**			10.89	10
10	Occurrence of flood and siltation				**10**	**2**		**7**		**2**	**3**	38.6	4

threatened (**NT**), the decline of **FMV** after last decay should be **40–50**, and least concern (**LC**), the decline of **FMV** after last decay should be <**40**.

9.7.5.1.12 Fish Magnitude Value (FMV): Assessment of Trend of Decline of Biodiversity

Fish magnitude value (**FMV)** has been designed and calculated from the vertical and horizontal logics. In this case, both the geographical distribution and temporal dimensions were taken care of while calculating the fish magnitude value (Patra et al. 2005; Mishra et al. 2009).

Table 9.20 Identification of causal factors responsible for depletion of *Ailia coila* (**N = 30**)

SL no.	Causal factors	Ranking by farmers I	II	III	IV	V	VI	VII	VIII	IX	X	RBQ values	Ranking of causal factors
1	Habitat destruction	**10**			**12**			**4**				**66**	**1**
2	Water pollution by wastes from human settlements			**9**		**2**				**2**		**29.03**	**6**
3	Use of nonrestricted nylon thread fishing	**1**		**1**			**6**		**5**	**5**		**21.51**	**8**
4	Introduction of exotic fish species gears		**4**	**4**				**7**				**31.68**	**5**
5	Fishing during breeding seasons	**1**		**1**		**2**	**6**		**3**	**5**		**25.47**	**7**
6	Ichthyotoxic materials (plants/chemicals)				**10**			**7**		**2**	**3**	**34.64**	**4**
7	Pesticides used for agriculture	**15**		**2**				**4**	**1**		**2**	**61.71**	**2**
8	Excessive and nonjudicious use of water							**6**		**7**		**12.54**	**9**
9	Sluggish behavior		**3**						**2**			**10.89**	**10**
10	Occurrence of flood and siltation		**3**	**11**	**2**				**5**			**47.52**	**3**

The contention was that fish species had declined not only over a geographical space but also over the time. Scoring by villagers showed low amidst a declining trend, and population of indigenous fish species in the natural habitats (irrigation canals, rivers, and its tributaries) has been reduced drastically between **1960** and **2000**.

The research outcome of trend analysis is used to depict the nature of decline of a species over decades through applying **participatory rural appraisal** (**PRA**) **techniques**. This is an innovative technique relying basically on the perceptual assessment by the fishermen of different age groups (**60** to **70** years old) about the decline of different fish species not only over time but also over distribution, **e.g.**, the fishermen assessed what have been the availability of a fish species in a given decade (**60s**) in terms of scores designed by themselves, and this score value [**yield Kg/**area of occupancy (**Km**)] was multiplied by the visibility range **vis-à-vis** the extent of their occurrence, say visible in **5–7** Km radii area, and this ultimately helps calculating the status of that very species in that decade.

This type of calculation over decades would delineate by what percentage the decline has been occurring since the benchmark decade. To avoid the biases in the perceptual assessment made by an individual farmer, the total score value of a group was divided by the number of members of that very group to have an interpolated value in the form of a mean:

$$\textbf{Mean of FMV} = .\textbf{Yeild X area of occupancy}.$$

Number of responding fish farmer. It was scintillating to observe that total fish magnitude values have been plunged abruptly for all the species under study between the decades of **1990** and **2000**. So special research thrust is to be organized to isolate the critical factors responsible for such an abrupt decline of all these local fish species.

The problems related to why fish population has gone a sharp decline over the decades were **12** in number [habitat destruction, use of nonrestricted nylon thread fishing gears, application of ichthyotoxic materials derived from local plants and chemicals used for agriculture, fishing during breeding seasons, water pollution by wastes from human settlements and industries, siltation, excessive and nonjudicious use of water, human population explosion, occurrence of flood, attack of disease (epizootic ulcerative syndrome), sluggish behavior of some fishes, and introduction of exotic fish species], among which in each cases, ten problems were restricted for the detection of causal factors responsible for depletion of fishes.

9.7.5.1.13 Plants Used for Stupefying Fish in Southern West Bengal, India

Fish harvesting with the help of toxic plant extract has been an age-old practice in various parts of the world. However, the techniques employed and plants/plant parts being used vary from country to country.

This practice of fish catching following traditional methods has recently attracted the attention of both scientists and entrepreneurs all over the world. A large number of plants used for stupefying fish from different Indian states have been reported by various workers, from the southern part of the state West Bengal, India, comprising of erstwhile three contiguous districts: Bankura, Midnapore [undivided; now Midnapore (East) and Midnapore (West)], and Hooghly (**22–23.3° N; 86–88.3° E**). Biogeographically, the whole area is a mosaic of different landscape types ranging from highly fertile alluvial plains to densely covered dry deciduous forests crisscrossed by six principal rivers **viz.** Dwarakeswar, Kansai, Keleghai, Rupnarayan, Silabati, and Subarnarekha – having a vast tract of seasonally or annually flooded riverine waterlogged depressions that support **104** fish species both migratory and local (Table 9.20).

A large cross section of rural fishing community, tribal and non-tribal, both having main agrarian economy, subsists on these aquatic ecosystems for livelihood during the lean periods of the year. To facilitate fish capture and to obtain good quantity of fish, they use local plants as fish-stupefying agent or fish poison.

These people love and enjoy fishing, often spending the whole day with their families even collecting a negligible amount of fish. For stupefying fish, selection of suitable site is very important (Mishra et al. 2009). In most of the cases, shallow water bodies, especially with slow-running water, is preferred over flowing streams since chances of plant parts used being swept away are greater in these lotic systems. The selected plants or plant parts are crushed directly in or near water body or crushed outside and thrown into the water.

The effect of fish poison makes fish perplexed momentarily, thus restricting its movement all of a sudden and finally forcing it to float on water surface, and thus capturing is facilitated and done. People's observation about stupefied fish is that plant-based ichthyotoxins cause damage to the eye and nerve. Fishes losing consciousness thus become sluggish and move uncertainly. Similar observations were also reported by present and earlier workers. This preliminary study (Mishra et al. 2002, Mishra et al. 2003a, b) during the six (**6**) seasons of two (**2**) consecutive years (**2000–2001**) reveals **14** ichthyotoxic plant species under **13** genera covering **11** dicot families (Table 9.3).

9.8 Conservation Strategy: Common People's Participation

There is an urgent need for conservation and revival of fishes whose populations have significantly declined. Possible conservation measures include eco-restoration, protective and preventive measure, in situ and ex situ conservation, and creation of mass awareness.

9.8.1 Conservation and Endangered Ecosystems Act

Sustainable bioresource management aims at maintaining a sound balance between optimum utilization of bioresources and simultaneous renewal of the same.

This should take into account the merit and demerits of resource utilization of the past and present, so that the need of the moment is satisfied and carrying capacity of natural resources is kept in reserve for fulfilling the future requirements. While sustainable bioresource management includes a broad spectrum of components, viz., better education; improved access to basic needs such as water, food, and shelter; etc., the viable ecosystems are seen as the basic life-support system. Successful ecosystem management for enhancing fish production usually depends upon the creation of partnership between the different users, managers, and beneficiaries. Thus, for sustainable development of common property resource, it is essential to involve local communities and other stakeholders.

It is often easier and more appropriate to work with existing groups of stakeholders rather than trying to create new interest groups. A mechanism should be sought for bringing together representatives of the various categories of stakeholders for participatory rural appraisal (**PRA**) to identify constraints and differences, resolve conflicts, review progress, make collaborative management decisions, etc.

The salient aspect of the approach is the local communities, their members are the experts, and the outsider is the learner one. Conservation is broadly defined as the management of a natural resource in such a way to provide assurance for the maximum benefit to the human being in the near future. Conservation embraces several components such as preservation, protection, maintenance, sustainable utilization, and eco-restoration.

9.8.1.1 Need for the Conservation

Natural resources are unlimited, this concept is no longer valid. All natural resources are finite in quantity and can be so overutilized or abused as to reach a point, where they are for all practical purposes no longer renewable. Therefore, all the so-called waste materials coming out from the utilization of natural resources should be recycled for its reuse.

It should always be remembered that biotic resources are, in fact, the object of human exploitation to meet the basic necessities of life and living. The exponentially growing human population is not only consuming the resources increasingly but also degrading the quality and disturbing the natural process of resource recycling.

Problems relating to conservation are the outcome of the following factors: rapid increase of human population, increasing industrialization and urbanization, degradation of environmental quality, excessive consumption of resources, and various types of pesticides used in agriculture for obtaining higher yield of food grain and vegetables in many states of India as well as in West Bengal, India.

A survey on the availability of pesticides used in the three districts in West Bengal indicates that chlorinated hydrocarbon pesticides are more frequently used by the farmers than any other category of pesticides. The chlorinated hydrocarbons are not easily broken down by the bacteria, other water quality parameters, and processes, but they are retained in soil, organic debris, bottom biota, aquatic insects, plankton, and fishes (Jhingran 1988). The simulated studies showed that several types of pesticides and inorganic fertilizers reduce the growth of fish even at sublethal levels and also reduce the frequency of fishes as well as the hatching success of the fertilized eggs of the fish (Konar 1977).

Sediment load represents one of the important aspects of hydrology of stream. These were probably due to dissolved solid, suspended solid, and bed load, **i.e.**, sand and clay deposition in the river bed. The relative importance of these categories depends on geological structure and climatic conditions of these areas where the river or drainage basin was situated (Michael 1988). The runoff from agricultural fields and denuded forests results in siltation of the riverine beds.

Dwarkeswar, Kansai, and Keleghai rivers and their tributaries were subjected to this kind of sedimentation load and siltation, which besides diminishing the flow of water results in the destruction of breeding grounds of fishes and benthic fauna, migration of fishes, and decline in overall productivity of these rivers and their associated water bodies.

In the abovementioned ecological background, the Ninteen (**19**) study sites belonging to 6 rivers, it was revealed that water of Midnapore (**SI**) in Kansai River, Khirai (**SIII**) and its associated water bodies, Dehati (**SIV**) and its surrounding wetlands in Keleghai, Garbeta (**SIX**) in Shilabati River, Rajgram (**SXIV**) and its associated water bodies, and Chandur (**SXVII**) and its adjoining water bodies in Dwarkeswar River were in good condition than other study sites.

The water quality of the Dwarkeswar River was assessed with the help of physicochemical as well as biological parameters. The results of this monitoring approach were presented as a case study of biological monitoring application in conjunction with physicochemical monitoring. It was observed from such study that the water quality of Dwarkeswar River at Rajgram and Chandur with their associated other water bodies was quite better than other sites of these river. The same results were noticed at different study sites, **viz., SI**, **SIII**, **SIV**, and **SIX** with their associated water bodies.

With the help of participatory rural appraisal (**PRA**) method, decade-wise trend analysis (from **1960** to **2000**), and fish magnitude value (**FMV**), it was confirmed that there has been severe decline in the freshwater fish fauna in Southwest Bengal in general and other food and game fishes in particular. Out of **103** species of fishes, **27** species were recognized as highly depleted fish population, among which *Nandus nandus* was subjected to abrupt decline between **1960** and **2000** (mean decline **86.15%**) followed by **Puntius** sarana (**83.78%**). The decline of **FMV** after 2000 in other species would have been as follows: *Rita rita* **62.82%**, *Batasio batasio* **41.76%**, *Lepidocephalus guntia* **48.13%**, *Mystus cavasius* **70.48%**, *Mystus vittatus* **63.20%**, *Ompok pabda* **74.64%**, *Ompok pabo* **79.46%**, *Wallago attu* **61.07%**, *Ailia coila* **76.13%**, *Clupisoma garua* **63.65%**, *Eutropiichthys vacha* **78.00%**, *Pangasius pangasius* **43.88%**, *Bagarius bagarius* **33.94%**, *Clarias batrachus* **41.27%**, *Arius gagora* **47.65%**, *Heteropneustes fossilis* **32.23%**, *Notopterus nopterus* **60.55%**, *Channa striatus* **36.27%**, *Amblypharyngodon mola* **46.37%**, *Anabas testudineus* **61.28%**, *Channa punctatus* **56.87%**, *Macrognathus pancalus* **43.85%**, *Aorichthys seenghala* **40.53%**, *Channa orientalis* **49.59%**, and *Tenualosa illisa* **46.30%** (Table 9.12).

Several anthropogenic activities in and around the riverine tracts such as large-scale water abstraction for channel irrigation; development of hydroelectric projects; construction of dams, reservoirs, and barrages; siltation; large-scale deforestation coupled with soil erosion and dumping and releasing of pollutants especially from the from industrial, agricultural, and municipal activities; using of pesticides and inorganic fertilizers; and such others have all had destructing effects on the fish stock of these rivers. Depth and width of channel and water current appeared to be very important factors of the environment.

Overexploitation coupled with loss of fish seeds were also other important factors for the decline of these fish genetic resources. All these factors led to the need for formulating out strategies of judicious exploitation of commercially important fish species, protection of these stocks from any sort of stress including pollution of the water and soil for improvement of the inland fishery, and conservation of the rich fish germplasm resources of this area.

9.8.1.2 Enactment of Endangered Ecosystems Act

The Endangered Ecosystems Act is a formal recognition of the importance of saving species which are threats of varied intensities. Alongside achieving some success, this act bears some lacunae as it does not pinpointedly address the major reasons that led to make species endangered, namely, the ecodegration or even loss of crucial ecosystems.

Thus, a level of diversity higher than biodiversity has appeared to be more effective in maintaining ecosystem diversity. Ecosystem diversity holds on several other ecosystems within short ranges, such as rivers with floodplains, associated wetlands, and even riparian forests on the bank of rivers, ensuring protections of such chain of ecosystems means protecting many threatened species.

Noss and Scott (1997) considered that critically endangered ecosystems suffer more than **98%** decline in the area which was formerly occupied normal diversity of organisms. They are of opinion that much could have been done to reduce the loss but continued pressures, especially the form the economic continue the pattern of transformation of many of the endangered ecosystems.

And all these have necessitated the enactment of Endangered **Ecosystem** Act, mainly with an aim at protecting the endangered species along with protecting endangered ecosystems in order to arrest further damage, recovering of eco-degraded critical ecosystems, and promoting more eco-monitoring and surveillance to generate useful baseline research information for better eco-management, protection, and conservation.

9.8.1.3 Threatened Categories

The earlier method of grouping of fishes into different categories, **viz**., threatened, extinct, endangered, vulnerable, and rare, has been put to different criticisms and thrown into a stressed situation for their subjective nature and abstractive dimension. The **IUCN Council** adopted the latest version in this regard (IUCN 2001; Red List **Categories and Criteria**, Version **3.1**) as a result of comments from the **IUCN** (IUCN 1994) and Species Survival Commission (**SSC**) memberships (IUCN 1998) and from a final meeting of the Criteria Review Working Group in February 2000, and the version incorporated changes of the earlier categories into nine categories, viz., extinct, extinct in the wild, critically endangered, endangered, vulnerable, near threatened, least concern, data deficient, and not evaluated. Critically endangered,

endangered, and vulnerable species belong to "**threatened**" category, and all the nine categories as per the **IUCN Version 3.1** have been defined as follows: the Endangered Species Act **(ESA)** of **1973**, reauthorized again in 1988, states that a species is endangered when it has been pushed to a point where it suffers an imminent danger of becoming extinct if protection is provided.

The act also provides provisions for the protection of the threatened species which are judged to be in jeopardy, but not on the brink of extinction. After assigning the status of threatened or endangered to a species, laws specify several penalty measures, such as substantial fines, for killing, damaging, and illegal trading of the species or its parts.

Extinct (EX) A taxon (species) is designated as extinct only after confirmation of the death of the last surviving individual of that species. The confirmation implies the failure of recording of the species after an exhaustive surveys on the habitats of that species eat appropriate times (diurnal, seasonal, annual), and also by framing survey schedule in tune of taxon's life cycle and life form.

Extinct in the Wild (EW) A taxon (species) is considered as extinct in the wild when any individual under the same species is not recorded from its from its population or habitat but only seen in the cultivated or domesticated forms.

Critically Endangered (CR) A taxon (species) appears to be critically endangered only when the best available evidence indicates that it meets any of the criteria (IUCN 2001) for critically endangered species, and it is going to be at an extremely high risk of extinction category in the wild if the causal factors continue operating.

Endangered (EN) A taxon (species) is named as endangered when the best available evidence indicates that it meets any one of the criteria (IUCN 2001) for endangered species because of the reduction of its numbers to a critical levels along with the drastic destruction of its habitats that the species is deemed to be in immediate danger of extinction.

Vulnerable (VU) A taxon (species) is assigned the treatment status as vulnerable only when it meets any one of the criteria for vulnerable based on existing available evidences (IUCN 2001), and it tends to move into the endangered category with in a short time if the causal factors continue operating.

Near Threatened (NT) A taxon (species) is appeared to be in the category of near threatened after completion of its evaluation against the criteria that does not qualify for the categories of critically endangered, endangered, or vulnerable now, and therefore, it is presumed that this species is likely to qualify for a threatened category in the near future.

Least Concern (LC) A taxon (species) is least concern when it does not fit to any threatened categories because of its higher abundance in its natural habitats.

Data Deficient (DD) A taxon (species) is data deficient because of the availability of dearth baseline research information regarding its abundance, distribution, and population in order derive at conclusion regarding the to make a direct or indirect assessment of its risk of extinction.

Not Evaluated (NE) A taxon (species) is denoted as not evaluated when no evaluation against the criteria for a threatened species is possible.

Based on the **PRA** (**participatory rural appraisal**) method, which includes several subcomponents such as **FMV** (**fish magnitude value**), **decade-wise trend analysis** (from 1960 to 2000), and **RBQ** (**rank-based quotient**) analysis, it has been possible by the research survey conducted in the Southwest Bengal of India to determine the conservation category of these **27** fish species which still enjoy considerable demand in the market by virtue of their nutrient status and palatability (Mishra et al. 2009).

Out of these **27** species, **2** species were ranked as critically endangered (**CE**), **3** species were categorized as endangered (**EN**), **9** species were remain as vulnerable (**VU**), **10** species were determined as near threatened (**NT**), and **3** species were listed as least concern (**LC**). From the **RBQ** analysis dealing with probable reasons for the causes of depletion of abundance of fishes were highlighted (Tables 9.7, 9.8, 9.9, 9.10 and 9.11) (Mishra et al. 2009).

A species has at least any of the following criteria:

1. Decline in the modes of occurrence and abundance of species in a striking rate
2. Absence of species in the geographic areas and habitats earlier inhabited by the species
3. Considerably lower presence of the total number of alive species having breeding potential
4. Expected proportionate declining of the density of the species in tune with the projected decline of the population along with the continuation of habitat destruction
5. Increased probability of extinction of the depleted population of the species within a specific number of years or future generations of the species

9.8.1.3.1 Rank-Based Quotient (RBQ): An Innovative Approach to Identify the Causal Factors of the Decline of Species Population

RBQ analysis was constructed mainly for five threatened fishes (two critically endangered, **viz.**, *Nandus nandus* and *Puntius sarana*, and three endangered, viz., *Ompok pabo*, *Ailia coila*, and *Eutropiichthys vacha*). In case of *Nandus nandus*, attack of disease (epizootic ulcerative syndrome) has considered as the most important factor followed by sluggish behavior, occurrence of flood and siltation, habitat destruction, pesticides used for agriculture, application of ichthyotoxic materials (plant products or synthetic chemicals), fishing during breeding seasons, use of nonrestricted nylon thread fishing gears, excessive and nonjudicious use of water, and introduction of exotic fish species. In case of *Puntius sarana*, habitat destruction has been considered as the most important factor followed by pesticides used for agriculture, water pollution by wastes from human settlements, fishing during breeding seasons, introduced exotic fish species, attack of disease (epizootic ulcerative syndrome), occurrence of flood and siltation, use of nonrestricted nylon thread fishing gears, sluggish behavior, and usage of ichthyotoxic materials (plant chemicals) for the depletion of this fish species.

RBQ values of *Ompok pabo*, *Ailia coila*, and *Eutropiichthys vacha* revealed that habitat destruction, occurrence of flood and siltation, pesticides used for agriculture, and fishing during breeding season are the first four causal factors for their depletion. In order to ensure conservation of all those rapidly depleting fish population, an attempt has been made for the artificial production of fish seeds employing updated induced breeding technology for two species of fish, **viz.**, *Puntius sarana* and *Mystus cavasius*, as a part of in situ conservation measure.

It has been possible to produce a good number of fish juvenile of this two threatened fishes and distribute to the farmers for their subsequent culture and propagation. Positive response was found for *Mystus cavasius* with a single dose of "**Ovatide**" with a single dose of **3 ml**/Kg to female and single dose of **1.5 ml/Kg** to male, and this appeared to be very significant for commercial seed production (Mishra et al. 2001).

Such program involving local fisherman along with their existing infrastructure may be further extended if different government agencies and research institutes can take up the responsibility to restore these natural resources. Therefore, this research venture with the financial assistance of the Department of Science and Technology and **NES**, Government of West Bengal, India, has taken into consideration the assessment of the environmental status of habitats of freshwater fishes, documentation of floral and faunal diversity including fishes, quantum production of fishery resources, studies on the biology of two threatened fishes, evaluation of the stress factors responsible for the depletion of fishery resources with the active participation of local people, assessment of conservation categories of selected fishes, and application of recent technology for the mass-scale production of seeds of already threatened fishes for their propagation and conservation.

9.8.2 Research Outcomes Based on PRA Methods

The research outcomes of research work for a period of **3** years, it was possible to document the diversity of flora (**113** species) and fauna (**254** species) of different freshwater wet-lands, rivers and their associated water bodies of Midnapore (West and East), Bankura and Hoogli districts of Southwest Bengal.

Physicochemical parameters of water and soil of these water bodies were also recorded to assess the environmental health of the habitats of different bioresources and also to understand the seasonal dynamics of those parameters and their relationships with the biological organisms. From the people perceptions, it was noted through **RBQ** analysis that the pollution of water by pesticides and heavy metals appeared to cause depletion and also loss of aquatic biodiversity, but it was not possible in this research venture to estimate the concentration of pesticides and heavy metals of water, soil, flora, and fauna of the studied aquatic ecosystems because such analysis would require more financial involvement.

A methodology has been devised based on participatory rural appraisal (PRA) method for the determination of the conservation categories of different commercially important finfishes. Out of such **27** finfishes, **24** species were found to belong under threatened category, of which **2** species were ranked as critically endangered (**CE**), **3** species were categorized as endangered (**EN**), **9** species were given the status as vulnerable (**VU**), and **10** species were determined as near threatened (**NT**).

For the propagation and simultaneous conservation of these threatened fishes, proper hypophyzation technique was applied (Mishra et al. 2001). Through the involvement of fisherman community, the main objectives of this research venture would be achieved if proper protection of fish habitats along with their genetic resources be done given due importance through different fisheries act and laws formulated by the Government of India.

9.9 Methods for Environmental Assessment of Study Areas

9.9.1 Application of Geographic Information System (GIS) Software for Mapping Study Sites

A **Geographical Information System (GIS)** as a repository of relational database acts as foundation for mapping and also for spatially distributed modeling.

All the data layers containing information of the topography, water features, forests, built structures, etc. can be stored in two forms: (**1**) Linear features, such as roads or rivers, are stored in vector form as a series of azimuths and distances tracing the path of the landscape feature. (**2**) Other attributes, such as topography, soil type, land use, or vegetation type, may be represented with vectors enclosing a polygon(s) or as matrices of position and attribute data in primary layers.

For example, topography is mathematically represented with a **digital elevation model (DEM)** with **x** and **y** as longitude and latitude, easting and northing, or **UTM** grid coordinates and **z** as elevation above the mean sea level. For other layers, identification numbers or attribute (integer) codes to differentiate soil, vegetation, or land-use types are the **z** value at a given (**x**, **y**) location.

Secondary layers are formed with the attribute data (as real numbers) pertaining to a primary layer (soil, thickness, infiltration capacity, and permeability or vegetation density, biomass, and condition). **GIS** layers also may be comprised of point data, such as building, wells, small water bodies, or other features of limited or discrete size (Wetzel and Likens 2004).

Point line and area (polygon) data can be combined to map and model interrelationships, calculate areas, or create new layers. For example, the **DEM** is routinely used to generate a slope layer (by calculating the change in elevation between adjacent grid cells). The slope layer can be used to estimate flow path (cell-to-cell linkages from the watershed divide to stream valleys) and contributing area (upslope of any given grid cell). These derivative layers are valuable for watershed modeling and management.

In sum, a **GIS** provides analytical and operational capabilities that were once limited to small experimental watersheds for a wide range of needs (Wetzel and Likens 2004):

(a) **In the initial stage** of **GIS** spatial database development, various analogue maps, which were in different scales obtained from different organizations, will be converted into digital format by using manual digitization method using GIS software.
(b) **In the second stage**, digital image processing of the satellite data will be carried out for extraction of pertinent information. The **IRS-P6** LISS-III and LISS-IV and **RADARSAT** data will be classified using supervised and unsupervised classification technique. The land-use maps of the **10**-year sequence will be prepared, and the original extent of the land-use change will be compared to compute an overall change patterns in each land-use class.
(c) **The third stage** focuses on bringing up all essential components of GIS platform for further processing and analysis.
(d) **The fourth stage** is with the objective of constructing composite information set to explain various queries in the spatial context through an integrated analysis of multidisciplinary data sets. **GIS** and land use are natural partners, as both of them deal with spatial data. The land-use change evaluation with respect to subsurface water changes will be provided.

GIS-based assessment for basic morphometric characteristics of lakes, streams, or rivers needs a reasonably accurate hydrographic survey facilitated with surveying equipment supplemented by obtaining aerial photographs in order to get the outline of the lake or streams. This is followed by the measurement of the shoreline sand formulated section by section. Most shoreline surveys use the traverse method, in which a series of points are connected by straight lines of known lengths and angles from each other.

Sophisticated methods of point location and survey are possible by the use of the Global Positioning System, where coordinates are determined from triangulation from satellites (Wetzel and Likens 2004). The salient features of the natural resources like rock outcrop patterns, lineaments, drainage patterns, vegetation patterns, soil phase and texture, and land-use patterns were interpreted and evaluated from **LANDSAT** products of different seasons and also the aerial photographs by using the interpretation elements like the shape, pattern, tone, and texture.

The courses of the prior stream channels were reconstructed and mapped from the aerial photographs, and a drainage map showing the present and prior stream channels was also prepared. The geomorphic characteristics of the meandering rivers, viz., amplitude, meander length, meander width, width of the existing channels, etc., were computed, and relationships between them were established.

The existing nadis and tanks were also interpreted and mapped. The changes in the land use, morphology of the landforms, and their changes due to degradation, flood, water pollution, etc. can also be detected and mapped from the temporal **LANDSAT** images of different seasons by additive color viewer (I2S), reflection projectors, and Zoom transfer stereoscope. The geomorphic characteristics of the catchments, meandering rivers, and sand dunes calculated in the laboratories were also checked in the field, and necessary corrections in case of any difference were made based on the ground truth of the land and vegetation resources.

The special characteristics of the landforms and vegetation were digitally analyzed and tabulated from two **computer compatible tapes (CCTs)** of **LANDSAT MSS** (bands **5** and **7**) – and with high-power computer with standard peripherals (image analyzer console, line printer, graphic display terminal, magnetic tape drivers, input scanner unit, solid-state refresh memory).

9.10 Selection of Study Sites: Design of Boring Activity at Onda, Bankura, District, West Bengal, India

9.10.1 Lithological Information: Prerequisite for Boring Activities

A survey based research study was conducted in the vier beds of fresh water riverine networks of south West Bengal Bengal, India in order to derive information of the lithological characteristics of the riverine beds and to develop understanding on the surface water-ground water interactions so that strategies for sustainable water resource management could be chalked out (Chakraborty et al. 2013). To understand the subsurface lithology and river morphology, **950** slim bores, **36** test wells, and **180** observatory wells were drilled in the selected study sites (Manbazar on Kansai River at Purulia District, and Onda, Joypur and Indus on Darakeswar River at Bankura District, West Bengal, India) on both the river beds (Kansai and Darakeswar) and on the river banks. At each site, **three test** wells were constructed. For each test well, **four** observatory wells were drilled, **2** were located at a distance of **185 m** away from each test well, and the rest **2** were drilled more than **30 m** away from the test wells. As far as yield is concerned, the starting point of the sampling site of the riverine stretch of Onda is being recommended as probable suitable for water withdrawal (Chakraborty et al, 2013).

Variations in the depth of slim bores: In Onda, out of **189** slim bores, the average depth of the layers varied from **2.5** to **8 mt**. In Indus, out of **186** slim bores, the average depth of the layers varied from **6** to **20 mt**. In Joypur, out of **191** slim bores, the average depth of the layers varied from **5** to **16 mt**. Yield test for Joypur block also has revealed the maximum possibility of water withdrawal from the starting point of the riverine bed, while at Indus, also the starting point appears to be the suitable site for water withdrawal. At Manbazar block, of Puroulia district of West Bengal, India on Kansai River, **5 km** downstream (site **3**) may be recommended for suitable water withdrawal. Drawdown test conducted also revealed maximum decline of water level is just a little more than 1 m after **72 h** of pump test with **100** mm pipe and **5** horsepower pump especially in the middle stream of Joypur and middle stream of Indus.

At Manbazar I, drawdown was found to be considerably low ranging from **11** cm at **5** km downstream to **18** cm at initial point. Sedimentological analysis has revealed almost similar sediment stratification in **three** sites of Dwarakeswar River of Bankura having a maximum percentage of coarse sand (**70%** at Onda, **72%** at Indus, **73%** at Joypur) and **65%** at Manbazar I on Kansai River followed by medium sand (**10%** at Onda, **11%** at Indus, **13%** at Joypur, and **15%** at Manbazar I). The silt, clay, fine sand, and gravels remained below 4% in all sites. However, at Manbazar I, higher occurrences of larger coarse sand blended with broken gravels have been noted in comparison to different sites of Dwarakeswar. Detailed textural analysis also showed higher percentage of sand (**97.6–99.75%**) in all sites except a few sampling sites at Manbazar I on Kansai River, Purulia District, where only big and small gravels were found.

The porosity of the sediment is a measure of how much water sediment contains, whereas permeability determines how fast water can flow through the soil. Effective porosity is the volume percentage of a sediment sample that consists of interconnected pores through which water can flow. In the present study, porosity ranged from **24%** to **46%** with the respective specific yield of **3%** to **19%**. The specific yield is controlled by grain size of different soil profiles. Specific retention decreases rapidly with increasing grain size. Specific yield is at its maximum in medium grained sands because porosity decreases with increasing grain size. Relationship between permeability and specific yield has shown that aquifers having a high specific yield tend to be more permeable.

This research study has also revealed the unconsolidated sediment profile of the rivers flowing through lateritic undulating landscape depicting higher permeability, porosities, and hydraulic conductivities (permeability in respect of water). Sediment, having higher sand percentage and gravels, especially at Manbazar I, shows higher hydraulic conductivities as in the present study areas. On the other hand, in order to understand groundwater flow rates and slopes of the water tables, the reciprocal of hydraulic conductivities in hydraulic resistance.

Good aquifers have a low resistance to flow and require only relatively shallow hydraulic gradients. The volume of water in an aquifer is calculated as the storage coefficient, termed as storativity, which is exactly the same as specific yield in water table aquifers. The storage coefficient is defined as the volume of water released from a unit volume of the aquifer for a unit decline in head.

The water quality parameters of both surface water and groundwater during different seasons and from different sites have been found to be well under permissible limits. Although negligible microbial load have been detected from the groundwater, water after normal treatment process can be served as drinking water. Analysis of pesticide residues is currently under way:

1. Fist (top) layer – medium sand, average **2 m** thickness, bright whitish color
2. Second layer – mud, average **2 m** thickness (within river course)

3. Third layer – courser sand, average thickness **2 m**
4. Fourth layer – very courser sand and gravel, average thickness **3 m**
5. Fifth layer – gravel and boulders or nodules size rock materials found in one cross-sectional part with **>0.5** m thickness

9.10.2 Sloping Pattern of River Bed

Average gradient of river bed within the selected river course is **10,500 m** length). Maximum elevation is **73.15200 m**, while minimum elevation is **57.6072 m**. So the gradient of this part = **(73.15200 m–57.6072 m)/10,500 m = 15.5448 m/ 10,500 m = 0.0014**. Maximum height of river bank (left) is **4.3** m; minimum height of river bank (left) **0.3 m** (almost flat with sand deposition); maximum height of river bank (right) **6.0** m; and minimum height of river bank (left) **0.5** m (almost flat with sand deposition).

9.10.3 Design of Boring Activities

Total number of cross section is **21**, total number of test bores **3**, total number of slim bores (in **30** m interval) **240**, average number of bores per cross section **11–12**, maximum boring depth **16.76** m, minimum boring depth **2.43** m, and average boring depth **6.7** m.

9.10.4 Pumping Cycles

Management of water resources in order to achieve sustainability takes into consideration the requirements of water both for ecosystem and for the human beings. Baseline information pertaining to interconnectivities between surface water and groundwater resources also help profusely to ensure successful water resource management as a prerequisite to achieve the goal, **i.e.**, sustainable water management of these resources. Management of groundwater and surface water systems in an integrated manner is impeded by the laws and policies of the countries concerned.

Most of the countries across the world have their separate rules and regulations for managing groundwater and surface water resources because of the significant seasonal variability of surface water supplies which contrasts to the fluctuation of groundwater use and supply on annual basis: groundwater budget and change in groundwater storage. The aquifers underlying the Central Valley receive water through deep percolation from the land surface, seepage from rivers and lakes, conveyance and delivery system recharge, and subsurface inflow from surrounding small watersheds. Outflows from the groundwater system to rivers and lakes, and to on-farm tile drains are primarily through groundwater pumping (Brush et al. 2013). The groundwater budget for the **C2VS**im model reports the beginning and ending of groundwater storages as well as inflows and outflows to/from the groundwater as summarized below (Dogrul 2012b):

1. **Deep Percolation**: Precipitation and excess irrigation water percolating through the unsaturated zone and entering the groundwater.
2. **Gain from Stream**: Water losses from streams that enter the aquifer system. Recharge from conveyance and delivery canal system and recharge to the aquifer from injection wells (artificial recharge).
3. **Boundary Flows**: Net inflow into the aquifer through the boundaries including flows from the small watersheds.
4. **Pumping**: Total pumping from the groundwater.
5. **Other Flow**: Water lost from lakes that enter the aquifer system, flow released out of groundwater storage due to subsidence, and flows from the groundwater into tile drains; these flows are generally not significant compared to the other flows, and they are grouped. When an aquifer is pumped, the water withdrawn is either taken out of storage, which means groundwater levels decline, or water is taken from other sources, including natural recharge, deep percolation, flows from boundaries of the groundwater basin, and seepage from stream.

9.10.5 Components of Pumping Test

Pump test is an important tool in the realm of hydro-geological study which mainly estimates the capacity and performance of the wells in order to highlight the potential and hydro-geological characteristics of both confined and non-confined aquifers. It also helps to understand the influence of well and aquifer's abilities to store and transmit water and also to ensure possible hydraulic connection to surface water.

A pumping test includes two major objectives: firstly, pumping of groundwater from a well maintaining a constant rate and, secondly, an estimation of the change in water level (drawdown) in the pumping well and any nearby wells (observation wells) or surface water bodies during and after pumping. The entire duration of traditional pumping test generally ranges from **24** to **72 h** depending on the extent of aquifers and other geohydrological features especially the interconnectivities among surface and subsurface water and groundwater (**Figs. 8.1 to 8.4**).

9.10.6 The Criteria for the Selection of Pumping Rates and Other Operational Components

The well should be pumped in accordance with the desired pumping rate which should not be rated above the pumping rate used during the test. Wells should not be

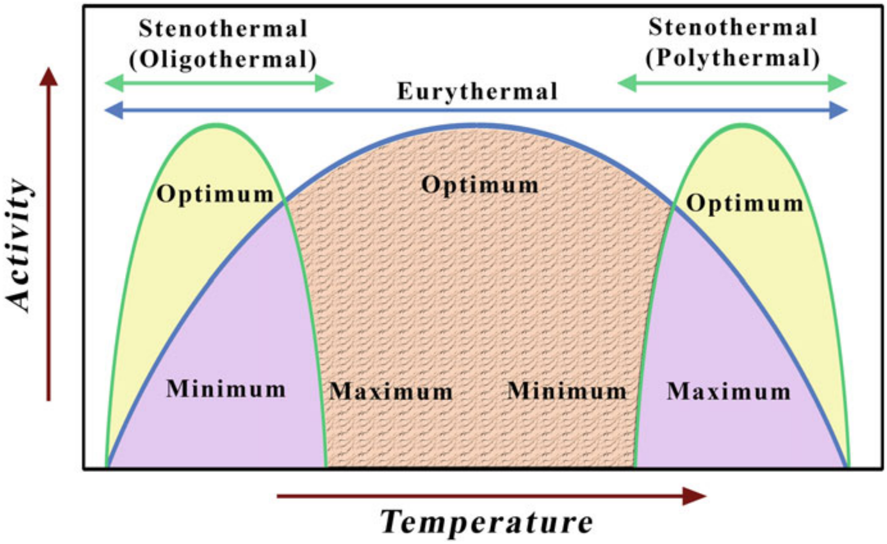

Fig. 9.1 Graphical representation depicting different levels of tolerability of living organisms

pumping of the well should be geared as per the recommendations of the manufacturers of the pump. This precaution can resist the prospective damage to the well or a sand/gravel pack developed around the well. For those wells which are constructed in unconsolidated sediments, having more sands and gravels than silts and clays with an open bottom (no well screen) should not be pumped at a rate which could cause the dislodging of aquifer materials and subsequent blocking up of the pump. In contrast, over pumping in the bedrock wells may result in exceeding the drawn down of water level over the uppermost level of water bearing fracture, because of the possibility of damaging the aquifer formation at the borehole and also in well interface due to the combined actions of water turbulence and turbidity of the available and extracted water also rendered hindrance, and inhibition to the pumping capacity (Fig. 9.1).

9.10.7 Boring Process: Sustainability of Water Resources

Extensive boring operations have been undertaken in the riverine beds of **four** selected study sites, viz., Onda, Indus, and Joypur on Dwarkeswar River in the Bankura District and Manbazar in the Kansai River in the Purulia District in the state of West Bengal, India. The term environmentally sustainable level of extraction is called sustainable yield of water (Figs. 9.2, 9.3, 9.4 and 9.5).

The exceeded level of water extraction from particular aquatic system inputs stress to the different ecosystem processes and the productive base of the resources. The groundwater extraction regime is estimated over a preplanned and

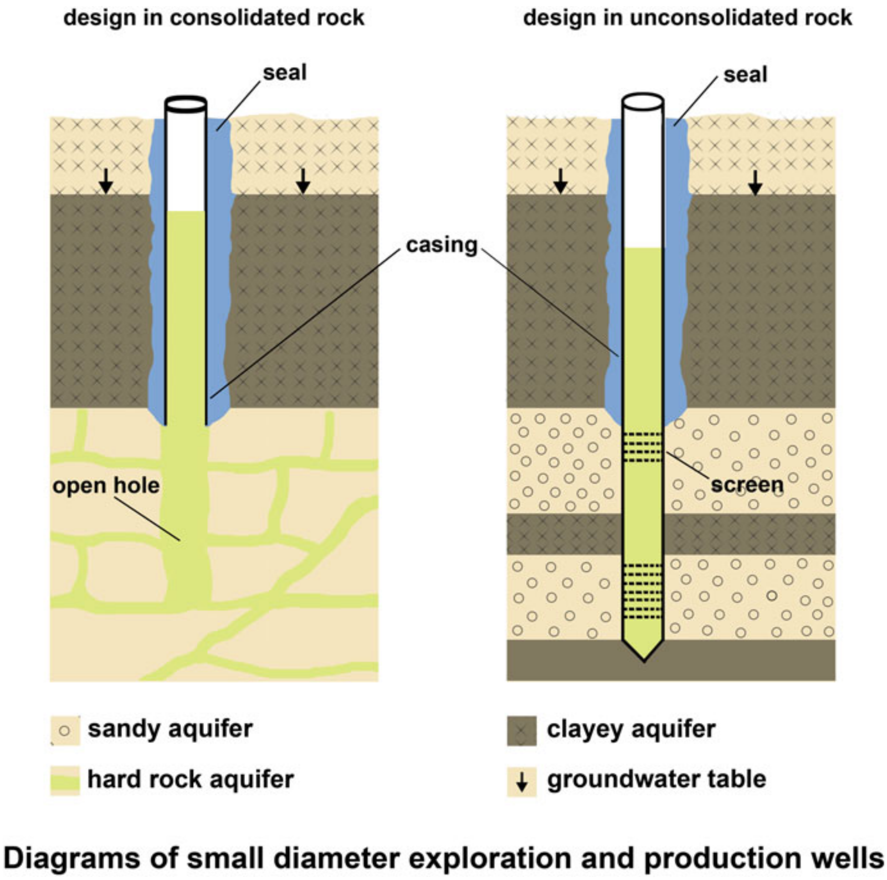

Fig. 9.2 Boring pipe insertion for studying cycle

predetermined time frame which tends to impose stress within the desired level and thereby save economic, social, and environmental values. The approach to the implementation of sustainable groundwater yield may include extraction regime of groundwater, acceptable level of stress on the groundwater, storage depletion trend to assess the lowering of water levels, and protecting dependent economic, social, and environmental values of estimated groundwater yield (Chakraborty et al. 2013).

9.10.8 *Extraction Regime*

The extraction regime concept is a regime of groundwater extraction under a set of management practices that are defined within a specified time and space. It is the maximum volume that is being withdrawn in any single year. Care should be taken to keep a balance between the rate of withdrawal and rate of recharging to compensate the loss.

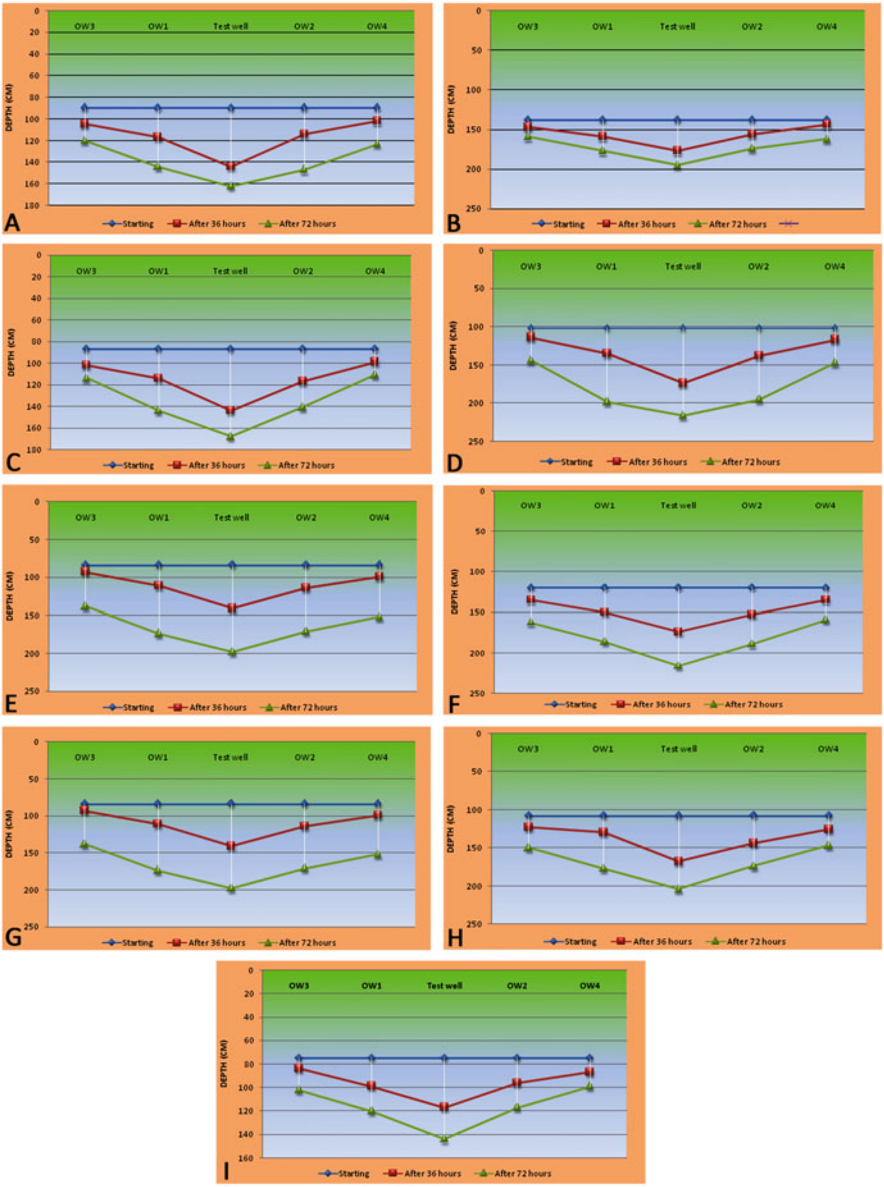

Fig. 9.3 Results of drawdown in the pumping cycle in 72-h duration

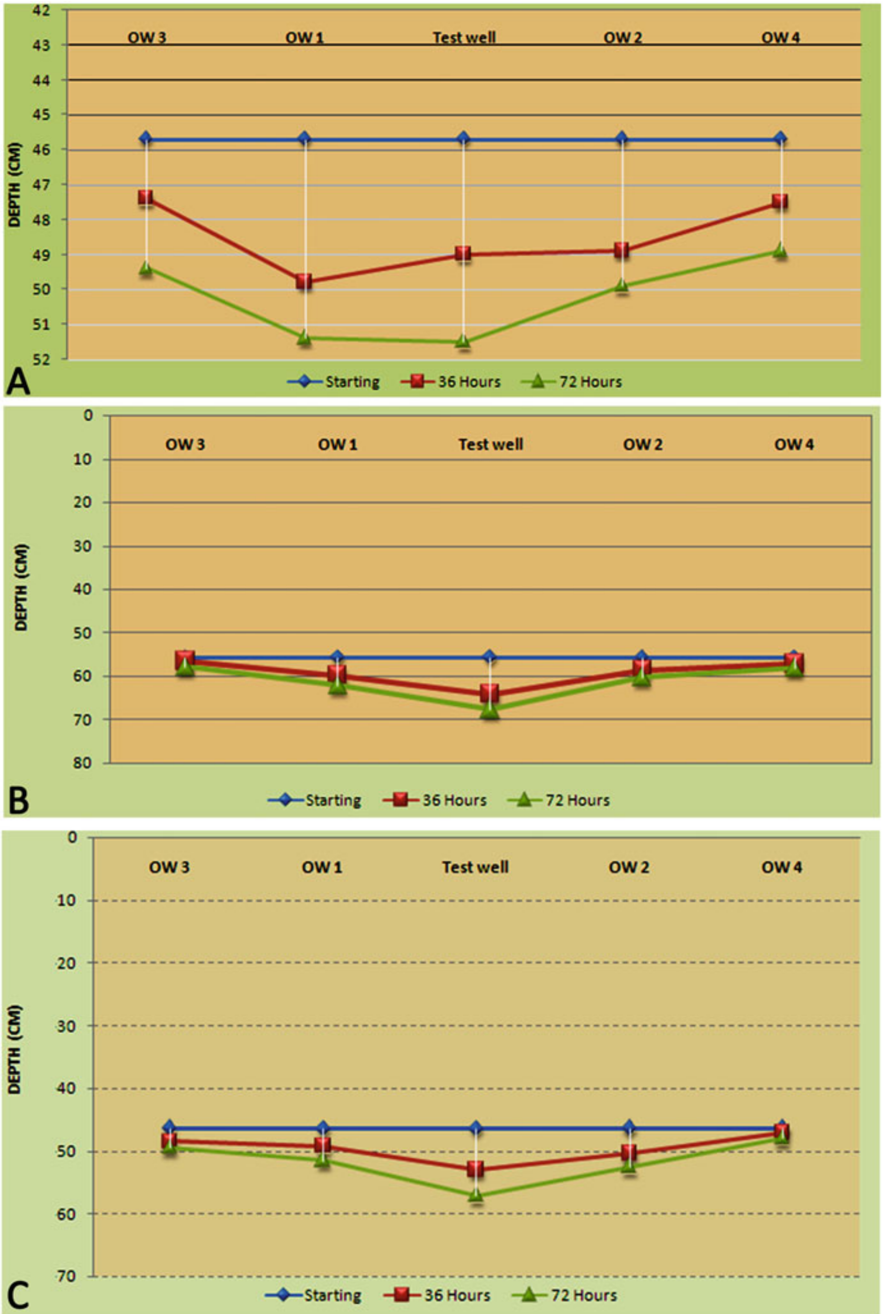

Fig. 9.4 Results of drawdown in the pumping cycle at specific site test well

Fig. 9.5 Photographs depicting different field activities relating to insertion of bore-well for studying pumping cycle (**A**–**D**): Geological, geomorphological and lithological assessment of different fresh water riverine beds of Bankura and Purulia , Districts of West Bengal; (**E** to **G**) Extraction and quantification of subsurface and ground water with the help of bore wells and test wells to generate data for the evaluation of draw-downs; (**H** to **L**) Field activities pertaining to the installation of bore wells and test wells at specified site mainataining requite distances based on the lithological assessment

9.10.9 Acceptable Levels of Stress

This approach recognizes that any extraction of groundwater of even any amount generally put different sorts of stresses on the total system of the water resources especially on the groundwater-dependent ecosystems. This concept being a controlling factor towards sustainable yield incorporates the necessity for trade-offs which in turn ensures balances among environmental, social, and economic requirements. In some cases, the stress may be temporary as the system adjusts to a new equilibrium. This holistic approach recognizes the interactions between aquifers and between surface and groundwater systems (Chakraborty et al. 2013).

9.10.10 Storage Depletion as a Parameter to Be Considered

The extraction of groundwater over any time frame results in an unacceptable depletion of storage which requires an assessment of that acceptability of that continuation and whether an intervening action is required to reduce the extraction. Major consideration in determining the acceptability of any specific level of storage depletion should be "**intergenerational equity**" and a balance between environmental matters identified in the National Principles for Provision of Water for Ecosystems and social and economic values. In this context, the sustainable yields of surface water can be estimated from the difference of the total available water resource and water used for the cological and anthopogenic purposes.

9.10.11 Sources and Values of Groundwater and Surface Water in the Studied River Basin

Potential and trend of water use: The combined estimated potential for the water supply of all the rivers in India is around **1900 Km^3** (billion cubic meters (**BCM**)), of which about **700 Km^3** is considered as the ultimate utilizable flow. Development of this scenario in respect of the water resources and its distribution in India is explained and correlated with the intensity and totality of rainfall of this country. Almost one-third of the potential rainfall of India is shared by the northeastern region; Cherrapunji in northeast of India, known as the wettest place in the world, remains underutilized. Out of so many rivers in India, the longest is the Ganga followed by the Brahmaputra, both of which are perennial rivers and cause massive damage to the plain river basin areas with floods every year (Environment Report, W. B. P.C.B. 2009).

9.10.12 Trends of Water Use

The total volume of water abstracted from all sources in and around the riverine networks of the Southwest Bengal, India, has increased substantially over the past 100 years. Total freshwater abstractions for agriculture ranked first followed by the utilization of water for public water supply. Household use is another important component of public water supply.

Industrial and commercial uses of water, both from the public water supply and by direct abstraction, have also been increasing during the couple of centuries because of the lack of awareness for environment. Besides, the total water resource and annual water budget of the districts understudy in the state of West Bengal, India can be assessed from the decadal data of in the forms of rainfall, runoff from neighboring regions, and replenishable groundwater (Chakraborty et al. 2013).

9.11 Values of Groundwater and Surface Water

The groundwater resources have multiple values, some of which are extractive while others are in situ. In considering trade-offs in resource values, due recognition should be given to environmental dependencies, and the risk of irreversible impacts and any decisions shall be made in accordance with the principles of ecological sustainable development. All surface water and groundwater originate from precipitation. Except during rainfall events, most surface water in streams and rivers is furnished by the slow release of groundwater as in the form of "**base flow**" which forms the primary source of water at the time of low river flow (Cartwright et al. 2005).

Groundwater serves as the prime supplier of water in most of the river basins including the present studied ones. A steady increase in the demand for the surface and groundwater resources during last couple of centuries has resulted in the river flow depletion and groundwater overdraft. Such steady increase in water use has threatened the sustainability of the water resources which has caused adverse effects of storage depletion, salinity intrusion, undesirable inter-aquifer flows, land subsidence, and groundwater contamination (Hanson et al.2002). Groundwater is also extracted for human uses in the river catchment areas and is now being considered as a possible alternative to direct stream extraction.

In the river basins having strong hydraulic connection between aquifers and river, groundwater extraction can lead to lowering of groundwater levels and a reduction of base flow from groundwater. In extreme cases, base flows can be reduced to an extent that the flow regime of the river catchment is fundamentally changed and rivers can shift from a perennial flow to an ephemeral flow regime (Glennon 2002).

9.11.1 Water Received as Runoff from Upstream Region

The quantum of runoff into geographical region lying in a particular basin is the runoff from the geographical region that lies upstream in the same basin. Treating the entire upstream region of the basin as a single entity and assuming that there is no flow of water from one basin to another, the runoff from the upstream region into the region at hand in a particular season can be evaluated following the undermentioned guideline (Environment Report, WB Pollution Control Board 2009):

Runoff from upstream region in current season = total water resources in upstream region in current season + quantity of previously intercepted water released in current season – evapotranspiration from upstream region in current season – infiltration in upstream region in current season – water intercepted in upstream region in current season, where total water resources in the upstream region in this season = rainfall in upstream region in current season + groundwater draft and discharge in upstream region in current season. Thus, runoff received from upstream region in current season = rainfall in upstream region in current season + groundwater discharge/

draft in upstream region in current season + quantity of water released from storage in current season – water intercepted in the region in current season – infiltration in the region in current season – evapotranspiration from the region in current season.

Precipitations tend to accumulate on the surface of the land and subsequently overflow the land surface as runoff, when the soil is saturated with the infiltration processes and capacity. The timing of runoff depends on the rate of precipitation over time as well as the infiltration capacity curve for a particular setting. In the study undertaken in the Southwest Bengal, India, it has been observed that the initial runoff was in the form of sheet flow over unchanneled ground, much of which ultimately on reaching the gullies and river channels drain large volumes of runoff loaded with eroded sediments to estuaries and then to ocean through the riverine networks (Chakraborty et al. 2013).

9.11.2 Groundwater–Surface Water Relationship

Groundwater flows through the subsurface and discharges to springs, lakes, rivers, and oceans. Groundwater flows on reaching to river beds, into the ground mostly by percolation and infiltration. These types of rivers may be hydraulically either connected to or disconnected from groundwater. Hydraulic connection implies surface water moves into the groundwater domain and vice versa, without encountering barriers to flow or unsaturated zones.

Effluent rivers occur mostly in the tropical humid regions of the world having the saturated water table very close to the land surface. These effluent rivers may become influent during the period of flooding, when the water levels within the rivers swell up and flow over the normal level with more currents and much faster flows than groundwater. Elevated river levels force some amount of water to seep into the channel banks.

Rivers may be effluent along some stretches and influent along others. A river flowing down a mountain may start out effluent but become influent near production wells that pump groundwater and induce infiltration of river water. Groundwater levels can be used for assessing the gaining or losing status of a surface water body. Higher groundwater levels (compared to the surface water elevation) usually indicate the surface water body is gaining groundwater. Conversely, lower groundwater levels often coincide with losing surface water conditions. Surface water that seeps into the ground can be an important source of groundwater recharge.

The present study has unearthed both subsurface and groundwater distributions of different study sites of Dwarkeswar and Kansai river beds. Conclusion: The research project has investigated the geomorphological, lithological, hydrobiological, microbiological, socioeconomic, and biological characteristics of the proposed study areas in order to evaluate the existing surface and subsurface flow characteristics so as to formulate and implement effective water recharge strategies incorporating government and public involvement.

Water is a "**common property resource**"; hence, for its effective distribution among people and proper utilization by people, people's participation is essential. For formulating policies that shall encompass people's participation, scientific investigation into the present status of the said resource is vital. Such studies not only generated awareness about current trends of the resource and the conditions pertaining to it but also shed light on the potential remediation and restoration strategies that can be adopted. The proposed study endeavors to do so with expert guidance from competent personnel and advanced infrastructural facilities of the proposing institution to find a solution to the growing problem of scarcity of freshwater resources in the arid tracts of the districts of Bankura and Purulia, West Bengal.

9.12 Sacred Grooves: Novel Approach for Biodiversity Conservation

The onward journey of human civilization on this planet from the primitive hunter-gatherers to the present high technology-based human society experienced a series of phases and the intervals in between different phases had encountered varied forms of anthropogenic activities and intervention on the natural set ups of the environment such as clearing of forests to give way to agriculture, industrial development with the help of new and newer scientific and technological innovations and inventions, and the experiences derived from such incidents ultimately paved the way for developing realization of the importance of natural gifts of nature, both living and nonliving ones. This has necessitated the initiation of pro-environmental thinking for the protection and conservation of biodiversity alongside several natural surrounds for their own survival and well-being (Ehrlich 2002). Human civilization now faces a number environmental crisis such as global warming, eutrophication, acidification, etc., out of which depletion or loss of biodiversity has appeared to be an important one because the very existence of humans is directly connected with it.

Virgin forests along with their biodiversity protected by the local people through generation after generation triggered by their cultural and religious beliefs manifested by different taboos and deities within tract of forest are designated as sacred groves These worships of natural patches of vegetation, valued and protected by the ancient societies, mainly based on their religious practices and cultural traditions known as sacred groves develop an interlinkages between man and his natural environment as well as his ecological prudence (Chandran and Hughes 1997).

Owing to the existence of vast diversity of ethnic culture in different parts of India, the nomenclatures of sacred groves also display variations of different local names (Gadgil et al. 2000). The Indian culture and traditions are closely intricate with the concern for the environmental conservation. Hence, there is a much scope to adopt this strategy for the conservation of biodiversity on religious ground in India.

In such context, the need of the hour is to develop a well-integrated and holistic approach involving existing status of the respective sacred grove to undertake ecological assessment of their roles for the conservation of biodiversity and also for formulating appropriate planning and strategies for their protection. Sacred groves being the reliable indicators of the ecological health of an area especially based on the potential of natural vegetation (Schaaf 1998) contribute profusely towards the well-being of the human society.

Sacred groves with assemblages of sacred trees act as the secured residences to so many birds and mammals and thereby facilitate conservation process of living organisms (Islam et al. 1998). Besides, a number of ecosystem services are provided by the sacred groves and maintain the desirable health such as conservation of soils, maintenance of hydrological cycle, restoration of soil erosion, availability of water of desired quality, natural dispersal of seeds of useful species, hindrance to habitat destruction, conservation of the viable population of pollinators and predators, etc.

The sacred groves also act as the source of propagules which enable the indigenous flora and fauna to flourish alongside preserving the cultural and ethical especially through indigenous knowledge of generations (Ramakrishnan and Ram 1988; Godbole et al. 1998; Godbole and Sarnaik 2004) (Figs. 9.6 and 9.7).

In such context, the following significant points can be highlighted with regard to developing proper awareness so that viable options can be developed for sustaining the economic condition of the peoples involved in the conservation of sacred grooves:

1. The traditional beliefs and knowledge should be provided with more attention in the process of protection and conservation of sacred forest patches including relict vegetation along with other biodiversity components of the concerned area.
2. The ongoing conflicts and contradictions between the traditional, local, or regional beliefs and the uprising of a number of the so-called economic and social issues to render the sacred grooves less effective should be amicably settled taking the local people into confidence in order to ensure sustainable eco-management of sacred groves and sacred sites.
3. Sacred groves having more unique in respect of their sizes, extent, and operational policies should be brought under the "**protected area network**" in order to strengthen the existing conservation strategies.
4. Attempts should be made to create mass awareness programs in order to make the peoples acquainted with and realized about the different ecological services rendered by sacred grove needs so that they should be convinced that the conservation of groves is of utmost essential for their sustenance.

9.13 Ethnozoological Potential of Animal Diversity

Since ancient times, different body parts and organs of animal bodies have been in use as medicinal substances by different groups of peoples having different cultures residing in different parts of the Earth. The twenty-first century is an era in which a

Fig. 9.6 Different sites of sacred grooves: (**A**) Chilkigarh Kanak-Durga Temple in the Jhargram District of West Bengal, India; (**B**) within Kuldiha Forest Sanctuary in the State of Odisha, India; (**C**) at Lodhasuli Forest of Jhargram District, West Bengal, India; (**D**) Idols of Bonbibi at Sundarbans, West Bengal, India; (**E**) near Galudih Subarnarekha Dam in the State of Jharkhand, India; (**F**) a typical tree sacred groove near Jharkhand and West Bengal border, India; (**G**) an artistic manifestation of the shelter built by local indigenous people depicting their traditional culture in tune with their natural settings; (**H**)–(**I**) local indigenous people by the side of Subarnarekha River, soldiers of sacred grooves, the custodian of nature and natural resources

great deal of effort and resources are being invested in the research of medicinal plants around the world. These studies are based mainly on historical, ethnic, and traditional sources of information (Costa-Neto 1999). The usage of animal extracts, products, and even secretions as medicines is thought to have coevolved with the evolutionary pathways of human beings and reached its highest acceptability during medieval period, which enjoys its existence in the present-day folk medicine across the globe (O'Hara-May 1971). India, with its diverse cultures and ethnicities, accommodates several isolated aboriginal human populations who have been practicing age-old healthcare systems (Modak et al. 2015).

One estimate made by the **World Health Organization (WHO)** has revealed that 80% of the world's population depend on traditional medicine for primary healthcare (Ekor 2013). The significance of recording the faunal biodiversity does not restrict only on the roles of wild fauna, both chordates and nonchordates in the food chain–food web dynamic of the riverine ecosystem, but also their contribution

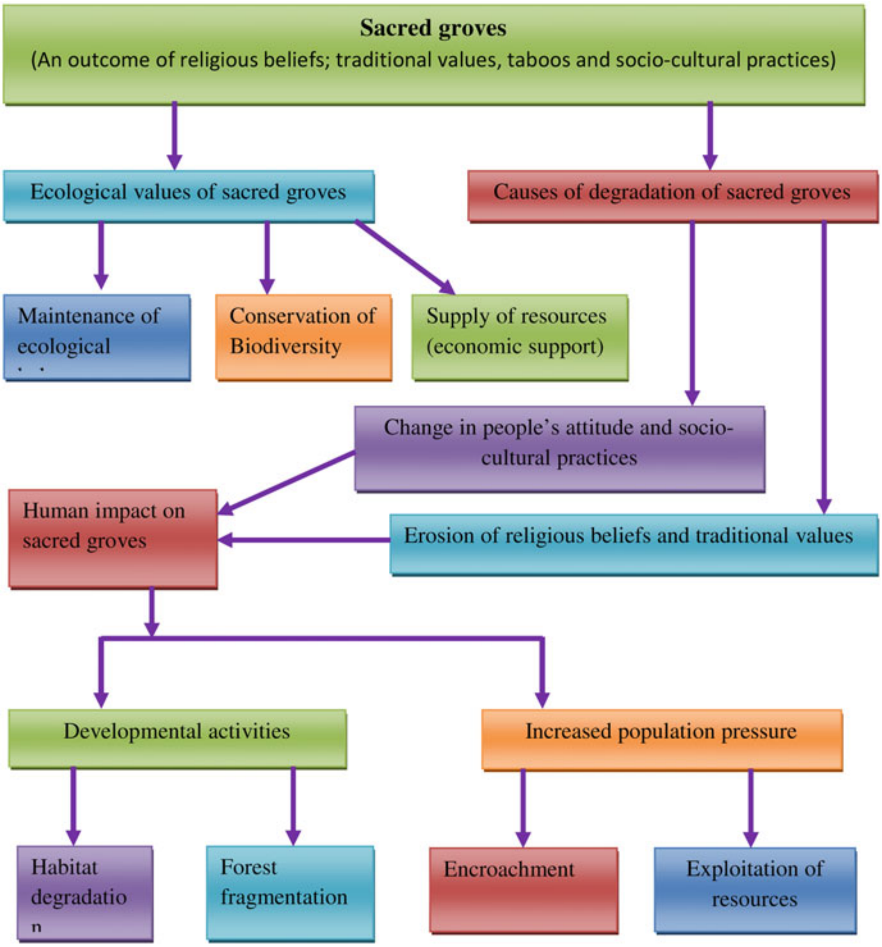

Fig. 9.7 A flow chart depicting different interconnected components for conservation of nature by scared grooves

in providing a lot of ingredients and commodities to the local peoples for the human healthcare purposes.

A new subject has emerged, known as ethnozoology, which mainly focuses on identifying natural products as ethnomedico-biologicals of the human healthcare system (Farnsworth 1990). These modes of medical treatment practices are preferred by local community over conventional treatments because ethnomedicines are cheaper, readily available, and efficacious and have fewer side effects (Modak et al. 2015). Many wildlife products are also used for ceremonial and religious practices as well as fetishes. Knowledge about animals that were used for remedial purposes in the past and are still used as such to the present day is part of traditional and ethnic medicine. Its importance lies in its fostering for better understanding of this phenomenon from historical, economic, sociological, anthropological, and environmental viewpoints throughout bygone centuries.

Several biomaterials from different faunal components have been in use for the biotherapy of human beings since the inception of human civilization such as the usage of blood of the black caiman (*Melanosuchus niger*, Spix 1825) for the treatment of epilepsy and cardiac problems and smashed products of the bodies of the ant species belonging to genus *Pseudomyrmex* for the treatment of toothache. The more potentiality of poisons as antipoison becomes more in the more poisonous animals (Werner 1970). El-Kamali (2000) has recorded **23** animals that are used as sources of remedies in the Sudanese traditional medicine. For example, external application of the fresh manure of a dromedary (*Camelus dromedarius* [Linnaeus 1758]) to the affected parts relieve and alleviate arthritis; use of honey can heal to some extent hepatic and gastrointestinal disorders, gastric ulcers, and wounds; the fats of the lion (*Panthera leo* [Linnaeus 1758]) and hyena (*Crocuta crocuta* [Erxleben 1777]) have been in use topically to alleviate abdominal pains; and the tusks of hippo (*Hippopotamus amphibious* [Linnaeus 1758]) are used for aphrodisiacs and ornamentals.

The drug development from a component of snake venom can be made successfully (Wied 1824). Administration of the aqueous extracts of shredded skins of *Naja naja* on pregnant female rats cause a decrease of urinary volume in a dose-dependent manner, increase urinary calcium output, reduce urinary magnesium, and increase urinary creatinine output (Mukherjee et al. 2013, 2019).

The choice of animal species in trado-medicinal preparations is guided by several factors, some of which include (**i**) the recognized bioactive ingredient(s) in the animal part, (**ii**) some behavioral ecological tendencies naturally associated with the animal or the concerned part, (**iii**) some mythological conceptions surrounding the animal, and (**iv**) the array of complimentary ingredients, faunistic or floristic, that oftentimes possess some behavioral ecological tendencies complimentary to that of the main fauna species as far as the condition to be treated is concerned.

The potentials of nonchordate metazoans for therapeutic use of leeches, one interesting annelids mostly prefer to live in the humid moist places in association with hydrophytes and also with the sediments, have been in use for treating some health problems of human beings such as abnormal swellings, piles, inflammatory abscess, skin diseases, rheumatoid arthritis, eye diseases, poisonous bites, erysipelas, etc. Insect-derived drugs are used in the treatments of immunological, analgesic, antibacterial, diuretic, anesthetic, and antirheumatic properties (Ratcliffe et al. 2011). However, the efficacy and safety of these animal-derived medicines are required for proper eco-toxicological testing prior to their application in order to encourage a broader acceptance and application of alternative treatment strategies. Another primary constrains for the conservation efforts is the nonjudicious utilization of selected flora or fauna for the purpose of medicines of food and this is designated as is the threatening effects on wildlife diversity because of overharvesting of animals and animal-derived products (Schmeda-Hirschmann et al. 2014). Illegal hunting and poaching have led to the rapid decline of many animals in their natural habitat, and measures are needed for their conservation and sustainable utilization.

9.14 Peoples Participation: An Emerging Issue on Biodiversity Conservation

The introduction of Peoples Participation (**PP**) in water management is a long and challenging process aimed at solving complex environmental, economic, and societal problems and increasing the sustainability of decisions. The global biodiversity has been under intensive threats because of a multitude of reasons such as habitat destruction, several pollutants coming out from the activities of modern industrial society, human population explosion, unplanned urbanization, excessive combustion of fossil fuels, introduction of exotic species, overexploitation of some targeted species, and so on and so forth. The reasons of enunciation of such detrimental causes leading to the loss of biodiversity have found to have direct connections with the culture, the structure of the economies, and the sociopolitical status of the actors.

In such context, conserving of biodiversity is in need of the participation of those people who are required to interact and change their perceptions towards biosphere in a great number of ways in order not only to enrich their knowledge base but also to address the plurality of reasons before taking up actions for conservation. Besides, independent efforts must be replaced by a collective ones so that prime objective of conserving biodiversity as maximum as possible can be fulfilled. Negotiating and developing collective agreement among the peoples with negative and destructive approaches to biosphere have appeared to be difficult mainly for two reasons: **First**, differences among different actors endowed with inherent or acquired destructive attitudes and activities accelerating the pace of biodiversity loss make the target inherently difficult to find common ground for reducing the destructive modes of interactions. **Second**, peoples are required to simplify the complex problems of biodiversity loss and also to find out suitable avenues in order to facilitate the formation of collective venture because politics associated with combating and arrest of biodiversity loss has mostly carried out those groups of people who seek particular combinations of simple strategies to meet the self-interest of all ends with renewed directions. As the development of common community consensus for the biodiversity management decisions forms the main structure of conservation planning, peoples attach more importance on their self-interest to gain short-term return as their livelihoods are entirely dependent on biodiversity. All these have necessitated to undertake more holistic, sustainable, and long-term conservation strategies for the conservation of biodiversity.

Public participation (**PP**) from the different strata of human society for the effective management of environmental resources has emerged as an important environmental issue and was identified by the United Nations in the year 1993 as one of the seven key elements for the long-term environmental program. The potential benefits of **PP**, associated with water resource management, are the better-informed decision-making and more creative solutions, more acceptance of water management and water prices, fewer implementation problems, and also social learning of all involved (Mostert 2003).

The second important issue is the greater involvement of nongovernmental organizations (**NGOs**) involving local peoples to strengthen the intersectoral cooperation for the sustainable water management, environmentally and economically. In order to introduce and fully implement **PP**, one should start with training and education of all the interested parties involved in (a) changing the decision-making culture, (b) empowering citizens and their initiatives, (c) making water and environmental management transparent and responsible, and (d) creating a framework to find a common solution (Chakraborty and Majumber 1995; Ramkrishna et al. 2014; Gadgil et al. 1993; Devi 2000).

References

Allan, J.D. 2004. Landscapes and riverscapes: The influence of land use on stream ecosystems. *Annual Review of Ecology Evolution and Systematics* 35: 257–284.

Allan, J.D., and L. Johnson. 1997. Catchment-scale analysis of aquatic ecosystems. *Freshwater Biology* 37: 107–111.

Allan, J.D., D.L. Erickson, and J. Fay. 1997. The influence of catchment land use on stream integrity across multiple spatial scales. *Freshwater Biology* 37: 149–161.

An, L.H., K. Lei, and B.H. Zheng. 2014. Use of heat shock protein MRNA expressions as biomarkers in wild crucian carp for monitoring water quality. *Environmental Toxicology and Pharmacology* 37 (1): 248–255.

Andersen, L., W.H.L. Siu, E.W.K. Ching, C.T. Kwok, F. Melville, C. Plummer, et al. 2006. *Antioxidant enzymes as biomarkers of environmental stress in oysters in Port Curtis*, Technical report 70. Indooroopilly: Cooperative Research Centre for Coastal Zone, Estuary and Waterway Management (Coastal CRC).

Anon, 2001 (Principal Investigator: S.K.Chakraborty). Inventory of threatened fresh water fishes of Midnapore District with an emphasis on bioecological studies of selected carp fishes for conservation and propagation.Sanctioned by D.S.T. (Govt. of W. B.), India [Sanction No. 410/ST/P/S & T/1G-4/99, dated, 29.02.2000.].

APHA (American Public Health Association). 2005. *Standard methods for the examination of water and waste water*. 21st ed. Washington DC: American Water Works Association and Water Environment Federation.

Astorga, A., R. Death, F. Death, R. Paavola, M. Chakraborty, and T. Muotka. 2011. Habitat heterogeneity drives the geographical distribution of beta diversity: The case of New Zealand stream invertebrates. *Ecology and Evolution* 4 (13): 2693–2702.

Banerjee, S.M., P.K. Chakraborty, R.S. Dey, and S. Raha. 2009. Heat stress upregulates chaperone heat shock protein 70 and antioxidant manganese superoxide dismutase through reactive oxygen species (ROS), p38MAPK, and Akt. *Cell Stress and Chaperones* 14 (6): 579–589.

Bartram, J., and R. Balance. 1996. *Water quality monitoring – A practical guide to the design and implementation of freshwater quality studies and monitoring programmes*. Geneva: UNEP and WHO.

Battish, S.K. 1992. *Freshwater Zooplankton of India*, 1–233. New Delhi: Oxford and IBH Publishing Co.

Beavan, L., J.P. Sadler, and C. Pinder. 2001. The invertebrate fauna of a physically modified urban river. *Hydrobiologia* 445 (1): 97–108.

Begon, M., C.A. Townsend, and J.L. Harper. 2006. *Ecology: From individuals to ecosystems*. 4th ed. Oxford: Wiley- Blackwell.

Berzins, B., and B. Pejler. 1987. Rotifera occurrence in relation to pH. *Hydrobiologia* 147: 107–116.

———. 1989a. Rotifera occurrence in relation to temperature. *Hydrobiologia* 175: 223–231.

———. 1989b. Rotifera occurrence in relation to trophic degree. *Hydrobiologia* 182: 171–180.

———. 1989c. Rotifera occurrence in relation to oxygen content. *Hydrobiologia* 183: 165–172.

Blasco, F. 1977. Outline of ecology, botany and forestry of the Mangals of the Indian subcontinent. In *Ecosystems of the world.1: Wet coastal ecosystems. Elsevier*, ed. V.J. Chapman, 241–260. Amsterdam.

Brasil, S.H., D. Vicente, S. Helena, S. Ramos, and C. Joana. 2019. Net primary productivity and seasonality of temperature and precipitation are predictors of the species richness of the Domselflies in the Amazon. *Basic and Applied Ecology* 35: 45–53.

Brookes, A. 1985. River channelisation: Traditional engineering methods, physical consequences and alternative practices. *Progress in Physical Geography* 9: 44–73.

Brooks, J.L., and S.I. Dodson. 1965. Predation, body size, and competition of plankton. *Science* 150: 28–35. http://www.jstor.org/discover/10.2307/1717947.

Buckley, M.R. 2004. *The global genome question: Microbes as the key to understanding evolution and ecology*. Washington D.C: A.S.M. Press.

Cariwright, J. 2019. Ecologicalislands: Conserving biodiversity hotspots in a changing climate. In *Frontiers of ecology and the environment*, 1–10. Wiley Periodicals Inc. on behalf of the Ecological Society of America.

Cartwright, J.M., and W.J. Wolfe. 2016. *Insular ecosystems of the South-Eastern United States: A regional synthesis to support biodiversity conservation in a changing climate*, Professional Paper 1828. Reston: U.S.Geological Survey.

Chainy, G.B.N., B. Paital, and J. Dandapat. 2016. An overview of seasonal changes in oxidative stress and antioxidant defence parameters in some invertebrate and vertebrate species. *Scientifica* 2016.

Chakraborty, S.K. 2011. Mangrove ecosystem of Sundarbans, India: Biodiversity, ecology, threats and conservation. In *Mangroves: Ecology, biology and taxonomy*, ed. James N. Metras, 83–112. New York: NOVA Publisher.

Chakraborty, S.K., and A. Choudhury. 1994. Community structure of macrobenthic polychaetes of intertidal region of Sagar Island, Hooghly Estuary, Sundarbans, India. *Tropical Ecology* 35 (1): 97–104.

Chakraborty, S.K., and S. Majumder. 1995. Management of forest ecosystem of Arabari forest, Midnapore, West Bengal, India: A review of problems and prospects. *Journal of Save the Environment* 111 (11): 52–62.

Chakraborty, S.K., S. Giri, G. Chakravarty, S. Dam Roy, and A.K. Sadhu. 2005. Avian Fauna. In *Mangrove ecosystems: A manual for the assessment of biodiversity*, CMFRI Special Publication No. 83, 176–189. Kochi: Central Marine Fisheries Research Institute.

Chakraborty, S.K., Paul, A.K., Bandyopadhyay, J., Banerjee, D., Pakhira, H, Middya, S, Jana, S., Sahoo, P., Paria, K., and Bera, K. 2013. Sustainable water management in the drought prone riverine tracts of south West Bengal. *Journal of Ground Water Studies*, 1:11−34.

Chakraborty, S.K., Pakhira, H. and Pariya, K. 2021. Bio-monitoring and bioremediation of a trans-boundary river in India: Functional roles of benthic mollusks and fungi. (In Spatial Modelling and Assessment of Environmental Contaminants: Risk Assessment and Remediation; Edited by Shit, P.K., Adhikary, P.P. and Sengupta, D: Published by Springer Nature): 611–661.

Chandran, M.S., and J.D. Hughes. 1997. The sacred groves of south India: Ecology, traditional communities and religious change. *Social Compass* 44: 413–427.

Connell, J.H., and R.O. Slayter. 1977. Mechanism of succession in natural communities and their roles in community stability and organization. *American Naturalist* 111: 1119–1144.

Costa Neto, E.M. 2002. The use of insects in folk medicine in the State of Bahia, Northeastern Brazil, with notes on isects reported elsewhere in Brazilian Folk Medicine. *Human Ecology* 30 (2): 245–263.

Cummins, K.W. 1973. Catchment characteristics and river ecosystems. In *River conservation and management*, ed. P.J. Boon, P. Calow, and G.E. Petts, 125–135. Chichester: Wiley.

Cunha, E.J., and L. Juen. 2017. Impacts of oil palm plantations on changes in environmental heterogeneity and Heteroptera (Gerromorpha and Nepomorpha) diversity. *Journal of Insect Conservation* 21: 111–119.

da Silva Cantinha, R., S.I. Borrely, N. Oguiura, C.A. de Bragança Pereira, M.M. Rigolon, and E. Nakano. 2017. HSP70 expression in *Biomphalaria glabrata* snails exposed to cadmium. *Ecotoxicology and Environmental Safety* 140: 18–23.

David, J.H. Philips. 1970. The use of biological indicator organisms to monitor trace metal pollution in marine and estuarine environments – A review. *Environmental Pollution* 13 (4): 181–317.

Day, F. 1878. *The fishes of India, being a natural history of the fishes known to inhabit the seas and fresh waters of India, Burma and Ceylon*, 553–778. London: Bernard Quaritch.

de Bij, V.A., R. Breukel, and V.G. Van der. 2006. Long-term developments in ecological rehabilitation of the main distributaries in the Rhine delta: Fish and macroinvertebrates. *Hydrobiologia* 565 (1): 229–242.

De Pauw, N., and H.A. Hawkes. 1993. Biological monitoring of river water quality. In *River water quality monitoring and control*, ed. W.J. Walley and S. Judd, 87–111. Birmingham: Aston University.

Devi, S. 2000. *Sacred groves of Manipur*. Abstract, National Workshop on Community Strategies on the Management of Natural Resources, Bhopal. Indira Gandhi Rashtriya Manav Sanghralaya, Bhopal.

Dhanpathi, M.V.S.S. 2000. *Taxonomic notes on the rotifers from India (from 1889–2000)*, 1–178. Hyderabad: Indian Association of Aquatic Biologists.

Dieterich, A., U. Fischbach, M. Ludwig, M.A. Di Lellis, S. Troschinski, U. Gärtner, R. Triebskom, and H.R. Köhler. 2013. Daily and seasonal changes in heat exposure and the Hsp 70 level of individuals from a field population of Xeropicta derbentina (Krynicki 1836) (Pulmonata, Hygromiidae) in Southern France. *Cell Stress and Chaperone* 18 (4): 405–414.

Dodds, W.K. 1997. Interspecific interaction: Constructing a general neural model for interaction type. *Oikos* 78: 377–383.

Dodds, W.K., and J.A. Nelson. 2006. Redefining the community: A species based approach. *Oikos* 11: 464–472.

Dodds, W.K., K. Gido, M.R. Whiles, K.M. Fritz, and M.J. Matthews. 2004. Life on the edge: The ecology of Great Plains prairie streams. *Bioscience* 54: 207–218.

Doyotte, A., C. Cossu, M.C. Jacquin, M. Babut, and P. Vasseur. 1997. Antioxidant enzymes, glutathione and lipid peroxidation as relevant biomarkers of experimental or field exposure in the gills and the digestive gland of the freshwater bivalve Unio tumidus. *Aquatic Toxicology* 39 (2): 93–110.

Edmondson, W.T. 1959. *Fresh water biology*. 2nd ed, 1–1284. New York: Wiley.

Edmondson, W.T. 1959. Rotifera. In *Freshwater biology*, ed. W.T. Edmondson, 420–494. New York/London: Wiley.

Ehrlich, P.R., and A.H. Ehrlich. 1981. *Extinction: The causes and consequences of the disappearance of species*. New York: Random House.

Ehrlich, P.R., and H.A. Mooney. 1983. Extinction, substitution, and ecosystem services. *Bioscience* 33: 248–254.

Ehrlich, P.R., and E.O. Wilson. 1991. Biodiversity studies: Science and policy. *Science* 253: 758–762.

Eichner, T., and R. Pethig. 2005. Ecosystem and economy: An integrated dynamic general equilibrium approach. *Journal of Economics* 85: 213–249.

Fabbri, E., P. Valbonesi, and S. Franzellitti. 2008. HSP expression in bivalves. *Invertebrate Survival Journal* 5 (135): e161.

Fairweather, P.G. 1999. State of environmental indicators of river health: Conference on Green India exploring the metaphor. *Freshwater Biology* 41: 211–220.

Farnsworth, E.J., and A.M. Ellison. 1996. Scale-dependent spatial and temporal variability in geography of mangrove root epibiont communities. *Ecological Monographs* 66 (1): 45–66.

Ferrier, S., G. Manion, J. Elith, and K. Richardson. 2007. Using generalized dissimilarity modelling to analyse and predict patterns of beta diversity in regional biodiversity assessment. *Diversity and Distributions* 13 (3): 252–264.

Ficke, A.D., C.A. Myrick, and L.J. Hansen. 2007. Potential impacts of global climate change on freshwater fisheries. *Reviews in Fish Biology and Fisheries* 17 (4): 581–613.

Forney, L.J., X. Zhou, and C.J. Brown. 2004. Molecular microbial ecology: Land of the one-eyed king. *Current Opinion inMicrobiology* 7: 210–220.

Fridovich, I. 1995. Superoxide radical and superoxide dismutases. *Annual Review of Biochemistry* 64: 97–112.

Füreder, L., and J.D. Reynolds. 2003. Is Austropotamobius pallipes a good bioindicator? *Bulletin Français de la Pêche et de la Pisciculture* 370–371: 157–163.

Fuller, R.J., S.A. Hinsley, and R.D. Swetnam. 2004. The relevance of non-farmland habitats, uncropped areas and habitat diversity to the conservation of farmland birds. *Ibis* 146 (Suppl 2): 22–31.

Gadgil, M., F. Berkes, and C. Folke. 1993. Indigenous knowledge for biodiversity conservation. *Ambio* 22: 151–156.

Gadgil, M., P.R.S. Rao, G. Utkarsh, P. Pramod, and A. Chhatre. 2000. New meanings for old knowledge: The people's biodiversity registers program. *Ecological Application* 10: 1307–1317.

Ghetil, P.F., and O. Ravera. 1994. European perspective on biological monitoring. In *Biological monitoring of aquatic systems*, ed. S.L. Loed and A. Spacie, 31. 46. New York: Lewis Publishers.

Gidalevitz, T., V. Prahlad, and R.I. Morimoto. 2011. The stress of protein misfolding: From single cell to multicellular organisms. *Cold Spring Harbor Perspectives in Biology* 3 (6): 1–18.

Giri, S., and S.K. Chakraborty. 2012. Water quality assessment through the study of Coliform bacteria and heavy metals of river Subarnarekha in South West Bengal, India. *International Journal on Environmental Science* 3 (2): 225–232.

Giri, S., P. Pradhan, and S.K. Chakraborty. 2005. Water quality assessment through the study of coliform bacteria and heavy metals of river Subarnarekha in south West Bengal, India. In *Proceedings of national seminar on "Biodiversity studies on Zooplankton" and "National seminar on developments in limnology"*. Department of Zoology, Acharya Nagarjuna University.

———. 2008. Studies on hydrobiological status of Kansai and Dwarkeswar river in West Bengal, India. *Journal of Indian Fisheries Society of India* 40 (1): 59–64.

Glennon, R.J. 2002. *Water follies: Groundwater pumping and the fate of America's fresh waters*. Island Press.

Godbole, A., and J. Sarnaik. 2004. *Tradition of sacred groves and communities contribution in their conservation*, 1–60. Pune: Applied Environmental Research Foundation.

Godbole, A., A. Watve, S. Prabhu, and J. Sarnaik. 1998. Role of sacred grove in biodiversity conservation with local people's participation: A case study from Ratnagiri district, Maharashtra. In *Conserving the sacred for biodiversity management*, ed. P.S. Ramakrishnan, K.G. Saxena, and U.M. Chandrashekara, 233–246. New Delhi: UNESCO and Oxford-IBH Publishing.

Graham, L.E., and W. Wilcox. 2016. Green algae V Streptophyte algae (Charophyte algae, Charophyceans). In *Algae*, vol. 62 (9), 3rd ed., 678–679. LJLM Press.

Grover, J.P. 1989. Phosphorus dependent growth -kinetics of 11 species of fresh -water algae. *Limnology and Oceanography* 34: 341–348.

Guo, Z., L. Zhang, and Y. Li. 2010. Increased dependance of humans on ecosystem services and biodiversity. *PLoS One* 5 (10): e13113.

Gupta, S.K., and J. Singh. 2011. Evaluation of molluscs as sensitive indicator of heavy metal pollution in aquatic system: A review. *Journal of Institute of Integrative Omics and Applied Biotechnology* 2 (1): 49–57.

Hakanson, L. 1980. Ecological risk index for aquatic pollution control: A sedimentological approach. *Water Research* 14: 975–1001.

Hakkari, L. 1972. Zooplankton species as indicator of environment. *Aqua Fennica* 72: 46–54.

Halder Mallick, P.H., and S.K. Chakraborty. 2014. Biotic interactions of freshwater zooplankton community vis-a-vis climate change. In *Proceedings of the international conference on Green-India: Strategic knowledge for combating climate change – Prospects and challenges*, ed. Aneesa B. Khan, 214–229. Pondicherry University/Excel India Publishers.

Halder, P., G. Bhunia, P. Pradhan, S. Banerjee, and S.K. Chakraborty. 2007. Ecological gradients determining the diversity of Zooplanktons in the wetlands in lateritic tracts of South-West Bengal. *Zoological Research in Human Welfare* 5: 37–46.

Halliwell, B.H., and J.M.C. Gutteridge. 1986. Iron and free radical reactions: Two aspects of antioxidant protection. *Trends in Biochemical Sciences* 11 (9): 372–375.

Halliwell, B., and J.M.C. Gutteridge. 2007. *Free radicals in biology and medicine*, 1–888. Oxford, UK: Oxford University Press.

Hilty, J., and A. Merenlender. 2000. Faunal indicator taxa selection for monitoring ecosystem health. *Biological Conservation* 92: 185–197.

Hofmann, W. 1977. The influence of abiotic -factors on population dynamics in planktonic rotifers. *Arch. Hydrobiol. 8eih., Ergebn. Limnol.* 8: 77–83.

Hofmann, G.E., B.A. Buckley, S. Airaksinen, J.E. Keen, and G.N. Somero. 2000. Heat shock protein expression is absent in the Antarctic fish *Trematomus bernacchii* (family Nototheniidae). *The Journal of Experimental Biology* 203 (15): 2331–2339.

Hutchinson, G.E. 1967. *A treatise on Limnology. Vol. II. Introduction to lake biology and the limnoplankton*. Vol. 7, 1–31. New York: Wiley.

International Union for Conservation of Nature and Natural Resources, UNEP, WWF. 1980. *World conservation strategy: Living resources for sustainable development*. Gland: IUCN.

IUCN. 2002. *Red list of threatened species*. Gland: IUCN-WCU.

Izagirre, U., A. Errasti, E. Bilbao, M. Múgica, and I. Marigómez. 2014. Combined effects of thermal stress and Cd on lysosomal biomarkers and transcription of genes encoding lysosomal enzymes and HSP70 in mussels, *Mytilus galloprovincialis*. *Aquatic Toxicology* 149: 145–156.

Jackson, R.B., S.R. Carpenter, C.N. Dahm, D.M. McKnight, R.J. Naiman, S.L. Postel, and S.W. Running. 2001. Water in a changing world. *Ecological Applications* 11: 1027–1045.

Jackson, R.B., N. Fierer, and J.P. Schimel. 2007. New directions in microbial ecology. *Ecology* 88: 1343–1344.

Jayaram, K.C. 1999. *The freshwater fishes of the Indian region*. Delhi: Narendra Publishing House.

Jhingran, A.G. 1988. Potential and scope for development of inland capture fisheries resources of India. In *Conservation and management of Inland Capture Fishery Resources*, CICFRI Pub. Bull. No. 57, ed. Arun G. Jhingran and V.V. Sugunan, 7–19.

Jiang, J.G. 2006. Development of a new biotic index to assess freshwater pollution. *Environmental Pollution* 139: 306–317.

Karr, J.R. 1981. Assessment of biotic integrity using fish communities. *Fisheries* 6: 21–27.

———. 1991. Biological integerity: A long neglected aspect of water resource management. *Ecological Applications* 1: 66–84.

———. 1999. Defining and measuring river health. *Freshwater Biology* 41: 221–234.

Kasina, M., M. Kraemer, C. Martius, and D. Wittmann. 2009. Farmers' knowledge of beees and their natural history in Kakamega district, Kenya. *Journal of Apicultural Research* 48: 126–133.

Kolkwitz, R. 1935. *Pfanzenphysioiogie*. 3. Aufl. G. Fisher, Jena, 310 p.

Kolkwitz, R., and M. Marsoon. 1902. Grubdsatzliches die bensteilung des wassers nch seiner flora und fauna. *Mitt. Der Kniser, Prufan. Fur Wass. Und Abwass. (Berlin -Dahlem)*: 1–33.

Kolkwitz, R., and M. Marsson. 1908. Okologic der pflazlichen Saprobien. *Berichte der Deutschen Botanischen Gesellschaft* 26: 505–519.

Krebs, C.J. 1972. *Ecology: The experimental analysis of distribution and abundance*. New York: Harper & Row.

———. 2001. *Ecology: The experimental analysis of distribution and abundance*. 5th ed. San Francisco: Benjamin Cummings.

Krieger, D.J. 2001. *The economic value of forest ecosystem services: A review*. Washington, DC: The Wilderness Society.

Kwok, Kevin W.H., Kenneth Leung, Lui Mei yee, S.G. Gilbert, and S. Vincent K.H. Chu. 2007. Comparison of tropical and temperate freshwater animal species' acute sensitivities to chemical: Implications for deriving safe extrapolation factors. *Integrated Environmental Assessment and Management* 3 (1): 49–67.

Landis, G.N., and J. Tower. 2005. Superoxide dismutase evolution and life span regulation. *Mechanisms of Ageing and Development* 126 (3): 365–379.

Lange, C.R., and S.R. Lange. 1997. Biomonitoring. *Water Environment Research* 69: 900–915.

LaVerne, J.A., and S.M. Pimblott. 1993. Yields of hydroxyl radical and hydrated electron scavenging reactions in aqueous-solutions of biological interest. *Radiation Research* 135 (1): 16 23.

Ligeiro, R., R.M. Huges, P.R. Kaufmann, D.R. Macedo, K.R. Firmiano, W.R. Ferreira, D. Oliveira, A.S. Melo, and M. Callisto. 2013. Defining quantitative strem disturbance gradients and the additive role of habitat variation to explain macroinvertebrate taxa richness. *Ecological Indicators* 25: 45–57.

Liu, D., and Z. Chen. 2013. The expression and induction of heat shock proteins in molluscs. *Protein & Peptide Letters* 20 (5): 601–606.

Liu, M., and M. Post. 2000. Cellular responses to mechanical stress. Invited review: Mechanochemical signal transduction in the fatal lung. *Journal of Applied Physiology* 89 (5): 2078–2084.

Macedo, M.N., M.T. Coe, R. DeFries, M. Uriate, P.M. Brando, C. Neill, and W.S. Walker. 2013. Land-use-driven stream warming in southeastern Amazonia. *Philosophical Transactions of Royal Society B* 368: 1–9.

Maemets, A. 1983. Rotifera as indicators of lake types in Estonia. *Hydrobiologia* 104: 357–361.

Maity Dutta, S., S.B. Mustafi, S. Raha, and S.K. Chakraborty. 2014. Assessment of thermal stress adaptation by monitoring Hsp70 and MnSOD in the freshwater gastropod, Bellamya bengalensis (Lamark 1882). *Environmental Monitoring and Assessment* 186 (12): 8961.

Maity Dutta, S., S. Banerjee, S.B. Mustafi, S. Raha, and S.K. Chakrabortya. 2018. Biomonitoring role of some cellular markers during heat stress-induced changes in highly representative fresh water mollusc, Bellamya bengalensis: Implication in climate change and biological adaptation. *Ecotoxicology and Environmental Safety* 157: 482–490.

Martins, I.S., and H.M. Pereira. 2017. Improving extinction projections across scales and habitats using countryside species-area relationship. *Scientific Reports* 7 (12899): 1–7.

Masindi, V., and K.L. Muedi. 2018. *Environmental contamination by heavy metals*. Vol. 7, 115–133. Intechopen Publisher.

McFadden, and Keeton. 1995. *Some initial resources for identifying various groups of aquatic organisms Menhinick, 1964*. (McFadden and Keeton, 1995; Forney et al. 2004).

Menhinick, E.F. 1964. A comparison of some species-individuals diversity indices applied to samples of field insects. *Ecology* 45 (4): 859–861.

Menon, A.G.K. 1949. *Notes on fishes XLIV*. Nepal: Fishes from the Koshi Himalayas.

———. 1999. *Check list fresh water fishes of India, Records Zoological Survey of India*, Occassional Paper No. 17. Vol. 175, 1–366.

Metzger, D.C., P. Pratt, and S.B. Roberts. 2012. Characterizing the effects of heavy metal and Vibrio exposure on Hsp70 expression in *Crassostrea gigas* gill tissue. *Journal of Shellfish Research* 31 (3): 627–630.

Michael, R.G. 1968. Studies on the zooplankton of a tropical fish pond. *Hydrobiologia* 32: 47–68.

Michael, P. 1984. *Ecological methods for field and laboratory investigation*. New Delhi.

Michael, R.G., and B.K. Sharma. 1988. Indian Cladocera (Crustacea: Branchiopoda: Cladocera). Fauna of Indian and adjacent countries series. *Zoological Survey of India, Kolkata*: 1–262.

Mishra, S.S., Pradhan, P., and Chakraborty, S.K. 2001 Induced spawning of a siluroid fish Mystus cavasius (Hamilton, Buchanan) for its propagation. *Aquacult, 2*(2):169–176.

Mishra, S.S., Pradhan, P., Chakraborty, S.K and Bhakat, R. K. 2002. Traditional knowledge for catching fish in Southern West Bengal. Vidyasagar University. *Journal of Biological Sciences, 8*:92–94.

Mishra, S.S., Pradhan, P., Chakraborty, S. K. and Bhakat, R. K. 2003. Plants used for stupefying fish in Southern West Bengal. *Science and Culture, 69*(1–2): 87–89.

Mishra, S.S., P. Pradhan, S.K. Chakraborty, and R.K. Bhakat. 2003a. Plants used for stupefying fish in Southern West Bengal. *Science and Culture* 69 (1–2): 87–89.

Mishra, S.S., P. Pradhan, S. Kar, and S.K. Chakraborty. 2003b. Ichthyofaunal diversity of Midnapore, Bankura and Hoogly Districts, South West Bengal. *Records of the Zoological Survey of India* 220: 1–65.

Mishra, S.S., S.K. Acharjee, and S.K. Chakraborty. 2009. Development of tools for assessing conservation categories of siluroid fishes of fresh water and brackish water wetlands of South West Bengal, India. *Journal of Environmental Biology of Fishes* 84: 395–407.

Mishra, S., S.K. Chakraborty, S.K. Acharya, and G.C. Mishra. 2017. *Fish diversity and conservation: The approach and strategy*, 110068. New Delhi: Krishi Sanskriti Publication. ISBN: 978–93–85822-20-9.

Mizrahi, T., S. Goldenberg, J. Heller, and Z. Arad. 2014. Natural variation in resistance to desiccation and heat shock protein expression in the land snail *Theba pisana* along a climatic gradient. *Physiological and Biochemical Zoology* 88 (1): 66–80.

Modak, B.K., P. Gorai, R. Dhan, and A. Mukherjee. 2015. Tradition in treating taboo: Folkloric medicinal wisdom of the aboriginals of Purulia district, West Bengal, India against sexual, gynaecological and related disorders. *Journal of Ethnoparmacology* 169: 370–386.

Mohiuddin, K.M., H.M. Zakir, K. Otomo, S. Sharmin, and N. Shikazono. 2010. Geochemical distribution of trace metal pollutants in water and sediments of downstream of an urban river. *International Journal of Environmental Science and Technology* 79: 778–783.

Monserrat, J.M., P.E. Martinez, L.A. Geracitano, L.L. Amado, C.M. Martins, G.L. Pinho, et al. 2007. Pollution biomarkers in estuarine animals: Critical review and new perspectives. *Comparative Biochemistry Physiology Part C: Toxicology and Pharmacology* 146 (1–2): 221–234.

Montag, L.F.A., H. Leao, N.L. Benone, C.S. Monteiro-Junior, A.P.J. Faria, G. Nicacio, C.P. Ferreira, D.H.A. Garcia, C.R.M. Santos, P.S. Pompeu, K.O. Winemiller, and L. Juen. 2019. Contrasting associations between habitat conditions and stream aquatic biodiversity in a forest reserve and its surrounding area in the Eastern Amazon. *Hydrobiologia* 826: 263–277.

Mostert, E., C. Pahl-Wostl, Y. Rees, D. Searle, D. Tabara, and J. Tippett. 2007. Social learning in European river-basin management: Barriers and fostering mechanisms from 10 river basins. *Ecology and Society* 12: 19.

Mukherjee, N., 1995. *Perticipatory Rural Apprisal and Questionnaire Survey*. Concept Publishing Co. Delhi

Mukherjee, S., S.C. Dasgupta, and A. Gomes. 2013. Effect of *Naja naja* Laurenti shed skin extract on estrous cycle, hormone − cytokine profiles, histopathology of ovary and uterus of Swiss albino mice. *Indian Journal of Experimental Biology*, 51: 235−240.

———. 2019. Effect of aqueous extract of *Naja naja* Sp. shedded skin in pregnant female rats and its role on the growth and development in the pups. *Journal of Toxins* 5 (1): 1–5.

Muller, G. 1979. Schwermetalle in den sediments des Rheins- Veranderugen seitt 1971. *Umschan* 79: 778–783.

Muller, N., M. Ignatieva, C.H. Nilon, P. Werner, and W.C. Zpperer. 2013. Chapter 10: Patterns and trends in urban biodiversity and landscape design. In *Urbanization, biodiversity and ecosystem services: Challenges and opportunities: a global assessment*, ed. T. Elmqvist et al., 123–174.

Naiman, R.J., and H. De'camps. 1997. The ecology of interfaces: Riparian zones. *Annual Review of Ecology and Systematics* 28: 621–658.

Needham, J.G., and P.R. Needham. 1962. *A guide to study of freshwater biology*, 18–21. San Francisco: Holden-Day Inc.

Nolen, Ellen A.A., M. Garcia Susana, Gijs van Haaften, Soojin Kim, Alejandro Chavez, Richard I. Morimoto, and Ronald H. Plasterk. 2004. Genome -wide RNA interference screen identifies previously undescribed regulators of polyglutamine aggregation. *Proceedings of the National Academy of Sciences of the United States of America* 101 (17): 6403–6408.

Noss, R.F. 2001. Beyond Kyoto: Forest management in a time of rapid climate change. *Conservation Biology* 15: 578–590.

Noss, R.F., and A.Y. Cooperrider. 1994. *Saving nature's legacy: Protecting and restoring biodiversity*. Washington, DC: Island Press.

Odum, E.P. 1953. *Fundamentals of ecology*. Philadelphia: Saunders.

———. 1969. The strategy of ecosystem development. *Science* 164: 262–270.

———. 1971. *Fundamentals of ecology*. 3rd ed, 1–574. Philadelphia: W.B. Saunders Co.

Odum, H.T., and E.P. Odum. 2000. The energetic basis for valuation of ecosystem services. *Ecosystems* 3: 21–23.

O'Hara-May, Jane. 1971. Measuring man's needs. *Journal of the History of Biology* 4 (2): 249–273.

Paiva, V.H., P.L. Geraldes, V. Marques, and R. Rodriguez. 2013. Effects of environmental variability on different trophic levels of the North Atlantic food web. *Marine Ecology Progress Series* 477: 15–28.

Pakhira, H., and S.K. Chakraborty. 2005. Conservation categories of siluroid fishes in North-East Sundarbans, India. *Biodiversity and Conservation* 14: 1863–1876.

Pakhira, H., and S.K. Chakraborty. 2016. Diversity and distribution of Molluscs in Subarnarekha River, India with emphasis on identifying indicator species. *International Journal of Current Research* 8 (11): 42162–42164.

———. 2018. Community structure of benthic mollusks in contrasting ecozones of a transboundary river in India: An ecological interpretation. *International Journal of Life Sciences Research* 6 (3): 233–238.

Pantle, R., and H. Buck. 1995. Die biologische Uberwachang der Gewasser and die Darstellung der Eegelnisse. *Gas und Wasserjach* 96: 604.

Paria, K., S.M. Mandal, and S.K. Chakroborty. 2017. Simultaneous Removal of Cd(II) and Pb (II) Using a Fungal Isolate, Aspergillus penicillioides (F12) from Subarnarekha Estuary. *International Journal of Environmental Research* 12 (1): 77–86.

Parry, M.L., O.F. Canziani, J.P. Palutikof, P.J. van der Linden, and C.E. Hanson. 2007. *Climate change 2007: Impacts, adaptation and vulnerability*, 982. Cambridge: Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press.

Patra, M.K., S.K. Acharjee, and S.K. Chakraborty. 2004. Economic productivity of bheri fisheries in relation to some management factors in North-East Sundarbans, India. *Journal of the Inland Fisheries Society of India* 36 (1): 23–28.

Patra, M.K., S.K. Acharjee, and S.K. Chakraborty. 2005. Conservation categories of siluroid fishes in North-East Sundarbans, India. *Biodiversity and Conservation* 14: 1863–1876.

Pejler, B. 1983. Zooplankton indicators of trophy and there food. *Hydrobiologia* 101: 111–114.

Pejler, B., and B. Berzins. 1989. On choice of substrate and habitat in brachionid rotifers. *Hydrobiologia* 186/187: 137–144.

Pejler, B., and B. Berzins. 1993. On choice of substrate and habitat in bdelloid rotifers. *Hydrobiologia* 255/256: 333–338.

Péru, N., and S. Dolédec. 2010. From compositional to functional biodiversity metrics in bioassessment: A case study using stream macroinvertebrate communities. *Ecological Indicators* 10: 1025–1036.

Piano, A., C. Asirelli, F. Caselli, and E. Fabbri. 2002. Hsp 70 expression in thermally stressed Ostreardulis, a commercially important oyster in Europe. *Cell Stress and Chaperones* 7 (3): 250–257.

Pielou, E.G. 1966. The measurement of diversity in different types of biological collection. *Journal of Theoretical Biology* 13: 131–144.

Pradhan, P., and S.K. Chakraborty. 2006. Diversity of zooplanktonic rotifers of river Shilabati, West Midnapore District, West Bengal, India. *Aquaculture* 7 (1): 99–117.

Pradhan, P., and S.K. Chakraborty. 2008. Ecological study of rotifera and its application for biomonitoring freshwater riverine environment. In *Zoological research in human welfare*, Paper-31, 289–306. Zoological Society of India, Kolkata and Zoological Survey of India.

Pradhan, P., S.S. Mishra, R. Majumder, and S.K. Chakraborty. 2003. Environmental monitoring with special emphasis on bio-monitoring – A prerequisite for sustainable environmental management: A case study in Darwakeswar river of South West Bengal, India. In *Environment pollution and management*, ed. A. Kumar, C. Bhora, and L.K. Sing, 87–103. New Delhi: Ashish Publishing Corporation.

Radwan, S. 1976. Planktonic rotifers as indicators of lake trophy. *Annales Universitatis Mariae Curie-Sklodowska, sectio C – Biologia* 31: 227–235.

Ramkrishnan, P.S. 1996. Conserving the sacred from the species to landscape. *Nature and. Resource* 32: 11–19.

Ramakrishnan, P.S., and S.C. Ram. 1988. Vegetation, biomass and productivity of seral grasslands of Cherrapunji in North-East India. *Vegetatio* 84: 47–53.

Ramakrishnan, P.S., K.G. Saxena, and U.M. Chandrashekara, eds. 2014. *Conserving the sacred for biodiversity management*. New Delhi: UNESCO and Oxford-IBH Publishing.

Raut, S.K. 1981. Sex ratio in Viviparus bengalensis (Lamarck) (Gastropoda: Viviparidae). *Bulletin – Zoological Survey of India* 4 (1): 13–15.

Ratcliffe, N.A., C.B. Mello, E.S. Garcia, T.M. Butt, and P. Azambuja. 2011. Insect natural products and processes: New treatments for human disease. *Insect Biochemistry and Molecular Biology.* 41: 747–769.

Reddy, Y.R. 2001. Zooplankton Diversity: Freshwater Planktonic Copepoda with key to common Calanoid and Cyclopoid Genera in India. In *Water quality assessment, biomonitoring and Zooplankton diversity*, ed. B.K. Sharma, 174–189. New Delhi: Ministry of Environment and Forests, Government of India.

Regoli, F., M. Nigro, and E. Orlando. 1998. Lysosomal and antioxidant responses to metals in the Antarctic scallop Adamussium colbecki. *Aquatic Toxicology* 40 (4): 375–392.

Reinhard, E. 1931. The plankton ecology of the upper Mississippi, Minneapolis to Winona. *Ecological Monographs* 1: 397–465.

Roberts, R.J., C. Agius, C. Saliba, P. Bossier, and Y.Y. Sung. 2010. Heat shock proteins (chaperones) in fish and shellfish and their potential role in relation to fish health: A review. *Journal of Fish Diseases* 33 (10): 789–801.

Roques, A., W. Rabitsch, C. Lopez-Vaamonde, et al. Alien terrestrial invertebrates of Europe. In *Handbook of alien species in Europe*, ed. DAISIE. Dordrecht: Springer.

Root, R. 1967. The niche exploitation pattern of the blue-gray gnatcatcher. *Ecological Monographs* 37: 317–350.

Rotifera. *Animal resources of India – State of art*, 69–88. Z.S.I. Publications.

Sabarathnam, V.E. 1988. *Manual on field experience training for A.R.S Scientists*, Rajendranagar, Hyderabad 30. National Academy of Agricultural Research Management.

Sabarathnam, V.E., and Vennila Sengottaiyan. 1996. Estimation of technological needs and identification of problems of farmers for formulation of research and extension programmes in agriculture entomology. *Experimental Agriculture* 32 (01): 87–90.

Saksena, D.N. 1987. Rotifers as indicators of water quality. *Acta Hydrochimica et Hydrobiologica* 15: 481–485.

Sanyal, P., S.K. Chakraborty, and P.B. Ghosh. 2014. Phytoremediation of sewage-fed wetlands of East-Kolkata, India: A case study. *International Research Journal of Environmental Sciences* 4 (1): 80–89.

Sanyal, P., N. Bhattacharya, and S.K. Chakraborty. 2015. Biomonitoring of four contrasting wetlands of Kolkata, West Bengal based on zooplankton ecodynamics and biotic indices. *Journal of Environmental Protection* 6 (7): 683–699.

Schmeda-Hirschmann, G., C. Quispe, C. Theoduloz, and P.T. de Sousa. 2014. Antiproliferative activity and new argininyl bufadienolide esters from the “cururu” toad *Rhinella (Bufo) schneideri*. *Journal of Ethnopharmacology* 155 (2).

Shannon, C.E., and W. Weaver. 1949. *The mathematical theory of communications*. Urbana: Illionois University Press.

Sharma, B.K. 1983. The Indian species of the genus, Brachionus (Eurotatoria: Monogonta: Brachionidae). *Hydrobiologia* 104: 31–39.

———. 1992. Freshwater Rotifers (Rotifera: Eurotatoria). In *Fauna of West Bengal*, State fauna series, 3(13), 1–121. Calcutta: Zoological Survey of India.

———. 1993. Freshwater Rotifes (Rotifera: Eurotatoria). In *Fauna of West Bengal*, State Fauna Series, 3, vol. 13, 1–121. Calcutta: Zoological Survey of India.

———. 1998. In *Faunal diversity of India*, ed. J.R.B. Alfred, A.K. Das, and A.K. Sanyal, 57–70. Zoological survey of India, Environmental centre.

———. 2001. Biomonitoring and role of Rotifera. In *Water quality assessment, biomonitoring and Zooplankton diversity*, ed. B.K. Sharma, 83–95. Shillong: Department of Zoology, NEHU.

Sharma, K.K., and M. Saini. 2016. Macrobenthic invertebrate assemblage along gradients of the river Basantr (Jammu, J&K) in response to industrial wastewater. *International Journal of Environmental and Agriculture Research* 2 (5): 127–140.

Sharma, B.K., and S. Sharma. 1990. On the taxonomic status of some cladoceran taxa (Crustacea: Cladocera) from central, India. *Revue d'hydrobiologie tropicale* 23 (2): 105–113.

Sharma, S., and P. Sharma. 2010. Biomonitoring of aquatic ecosystem with concept and procedures particular reference to aquatic macro invertebrates. *Journal of American Science* 6: 1246–1255.

Sharma, A., et al. 1999. Studies on zooplankton community of the Tungabhadra river in Karnataka receiving domestic sewage from Harihar region. *Journal of Environment & Pollution* 6 (2&3): 161–166.

———. 2001. Biomonitoring and role of Rotifera. In *Water quality assessment, biomonitoring and zooplankton diversity*, ed. B.K. Sharma, 83–95. Shillong: Department of Zoology, NEHU.

Shaw, G.E., and E.O. Shebbeare. 1937. Fishes of Northern Bengal. *Journal Royal Asiatic Society, Bengal Science*: 1–44.

Shaw, M.R., L. Pendleton, D.R. Cameron, B. Morris, D. Bachelet, J. Klausmeyer, D.R. Conkin, G. N. Bratman, J. Lenihan, E. Haunreiter, C. Daly, and P.R. Roehrdanz. 2011. The impact of climate change on California's ecosystem services. *Climate Change* 109 (Suppl 1): S465–S484.

Siegloch, A.E., R. Schmitt, M. Spies, M. Petrucio, and M.I.M. Hernandez. 2017. Effects of small changes in riparian forest complexity on aquatic insect bioindicators in Brazilian subtropical streams. *Marine and Freshwater Research* 68: 519–527.

Simpson, E.H. 1949. Measurement of diversity. *Nature* 163: 688.

Sinha, R.K. 1992. Rotifer population of Ganga near Paba, Bihar(India). *The Proceedings of the National Academy of Sciences, India, Section B*: 313–322.

Sladecek, V. 1995. Rotifers as test system for pollution monitoring. In *Pollution studies*, ed. B.C. Rana. Karad: Environmental Publications.

Smith, G.L. 1979. *Proceedings, workshop in instreamflow habitat criteria and modelling*. Fort Collins: Colorado Water Resources Research Institute information series 40.

Sorensen, T. 1984. *A method of establishing groups of equal amplitude in plant sociology based on similarity of species content and its application to analyses of the vegetation of Danish commons*. Biol. Skr. (K. danskevidensk. Selsk. N. S.), 5, 1–34.

Stark, J.D., and Ian K.G. Boothroyd. 2000. In *New Zealand stream invertebrates: Ecology and implication for management*, ed. K.J. Collier and M.J. Winterbourn, 344–373. New Zealand Limnological Society.

Steinman, A.D., and R. Denning. 2005. The role of spatial heterogeneity in the management of freshwater resources. In *Ecosystem function in heterogeneous landscapes*, 367–387.

Strickland, J.D.H., and T.R. Persons. 1968. Determination of reactive nitrate. In *A practical handbook of seawater analysis*, 71–75. Fisheries Research Board of Canada, Bulletin 167.

Storey, K.B. 1996. Oxidative Stress: Animal adaptations in nature. *Brazilian Journal of Medical and Biological Research* 29 (12): 1715–1733.

Subba Rao, N.B. 1989. Freshwater Molluscs of India. In *Handbook zoological survey of India*, Calcutta XXIII, 1–289.

Suthar, S. 2009. Earthworm communities a bioindicator of aerable land management practices: A case study in semiarid region of India. *Ecological Indicators* 9 (3): 588–594.
Suther, S., A.K. Nema, M. Chabukdhara, and S.K. Gupta. 2009. Assessment of metals in water and sediments of Hindon River, India: Impact of industrial and urban discharges. *Journal of Hazardous Materials* 171: 1088–1095.
Talwar, P.K., and A.G. Jhingran. 1991. *Inland fishes*. Vol. 1 and 2. New Delhi: Oxford and IBH Publishing Co. Pvt. Ltd.
Thorp, J.H., and A.P. Covich, eds. 2001. *Ecology and classification of North American freshwater invertebrates*. 2nd ed, 1038p. San Diego: Academic Press.
Tomlinson, P.B. 1986. *The Botany of mangroves*, 414. Cambridge: Cambridge University Press.
Trivedy, R.K., and P.K. Goel. 1984. *Chemical and biological methods for water quality studies*, 1–215. Karad: Environmental Publications.
Verlecar, X.N., K.B. Jena, and G.B.N. Chainy. 2008. Modulation of antioxidant defenses in digestive gland of Perna viridis (L.), on mercury exposures. *Chemosphere* 71 (10): 1977–1985.
Vinson, M.R., and C.P. Hawkins. 1998. Biodiversity of stream insects: Variation at local, basin and regional scales. *Annual Review of Entomology* 43: 271–293.
Walkley, A., and I.A. Black. 1934. An examination of Degtjareff method for determining soil organic matter, and proposed modification of the chromic acid titration method. *Soil Science* 37: 29–38.
Wallace, J.B., and J.R. Webster. 1996. The role of macroinvertebrates in stream ecosystem function. *Annual Reviews of Entomology* 41: 115–139.
Wang, Y.N., H. Wang, X.W. Zhu, M.M. Luo, Z.G. Liu, and X.D. Du. 2012. Joint effects of water temperature and salinity on the expression of gill Hsp70 gene in Pinctada martensii (Dunker). *Ying Yong Sheng Tai Xue Bao* 23 (12): 3467–3473.
Wang, L., C. Yang, and L. Song. 2013. The molluscan HSP70s and their expression in haemocytes. *Invertebrate Survival Journal* 10: 77–83.
Wepener, V., J.H.J. Van Vuren, F.P. Chatiza, Z. Mbizi, L. Slabbert, and B. Masola. 2005. Active biomonitoring in freshwater environments: Early warning signals from biomarkers in assessing biological effects of diffuse sources of pollutants. *Physics and Chemistry of the Earth, Parts A/B/C* 30 (11): 751–761.
Werner, E.E. 1977. Species packing and niche complementarity in three sunfishes. *The American Naturalist* 111: 553–578.
Westlake, D.F. 1975. Macrophytes. In *River ecology*, ed. B.A. Whitton, 106–128. Berkeley: University of California Press.
Wetzel, R.G. 1992. Gradient-dominated ecosystems: Sources and regulatory functions of dissolved organic matter in freshwater ecosystems. *Hydrobiologia* 229: 181–198.
———. 2001. *Limnology: Lake and river ecosystems*. 3rd ed. San Diego: Elsevier, 1006 pp.
Wetzel, R.G., and G.E. Likens. 1991. *Limnological analyses*. 2nd ed, 1–391. New York: Springer.
Whittaker, R.H. 1972. Evolution and measurement of species diversity. *Taxon* 21: 213–251.
Wilhm, J.L., and T.C. Dorris. 1966. Species diversity of benthic macroinvertebrates in a stream receiving domestic and oil refinery effluents. *American Midland Naturalist* 76: 427–449.
Winner, J.M. 1975. Zooplankton. In *Studies in ecology*, River Ecology, ed. B.A. Whitton, vol. 2, 155–169. Oxford/London/Edinburgh/Melbourne: Blackwell Scientific Publication.
Woese, C.R., O. Kandler, and M.L. Wheelis. 1990. Towards a natural system of organisms: Proposal for the domains Archaea, Bacteria, and Eucarya. *Proceedings of the National Academy of Sciences of the USA* 87 (12): 4576–4579.
Wood, R., A.Y. Ivantsov, and A.Y. Zhuravlev. 2017, March. First macrobiota biomineralization was environmentally triggered. In *Proceedings of the royal society: Part B* (Vol. 284, No. 1851, p. 20170059). The Royal Society.
Zwart, D., and R.C. Trivedi. 1995. *Manual on integrated water quality evaluation*. RIVM, Bilthoven. RIVM Report 208023003, Appendix 6, 1–101.

Chapter 10
Conclusion

Abstract Life after originating around **3.5** billion years ago have led to the evolution of millions of species on the Earth and followed taxonomic hierarchy as species and subspecies, families, and genera. Each species has had to cope with nature's demands and compete with other species in order to survive, reproduce and perpetuate its own kind. Failing to accomplish this, it disappears and is gone forever. All the forces that produced changes and extinctions were natural and happened by chance. However, once humans began to control and alter their surroundings, the impact on such interventions on the environment have been proved to become very drastic and dramatic leading cause the loss of species.

Rivers being the reservoir of an array of biodiversity components in the flowing water ecosystem have been serving the sustenance of human beings since immortal by way of providing a lot of ecosystem services which have been threatened by human activities. Therefore, sustainable management of river ecosystem requires an integrated approach of involving different disciplines of science (physical, chemical, geological, biological, and mathematical) and also other branches of social science (sociology, economics, history, etc.) to pay more emphasis to restoration measures and also to reverse the ongoing environmental perturbation-mediated ecodegradation. Formulation of policies through adequate research and their implementation by governmental agencies seems pivotal to address the issues. Simultaneously, awareness at community levels and people's participation may also be essential to ensure sustained management programs for the effective maintenance and rejuvenation of surface and subsurface freshwater flows in and around river ecosystems as this ecologically potential and healthy freshwater ecosystems renders a wealth of goods and services for the society. River ecosystems with sound ecological health contribute a lot of ecological goods and services for the society, but the perception of human civilization should be better managed and oriented to sustain all these biodiversity-mediated benefits. An eco-management framework for ecologically sustainable water management alongside meeting the optimum needs of water for human beings alongside restoring the ecological integrity of affected river ecosystems by devising proper methods for storing and diverting water which include undermentioned steps.

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Eco-assessment and eco-manipulation of the riverine ecosystem using of biological criteria (biological integrity, ecological integrity, bioindicator species, etc.) have become popular across the world, but definite research evidences on the relationships between ecosystem degradation and biological response are still very scanty. A well-documented effort has been made in this **Volume -II** of the **book Riverine Ecology** on the present concept and values of biodiversity and evolution different conservation strategies alongside highlighting diversity and ecofunctionality of different biodiversity components (river-based microbes, riparian plants, macrophytes, phytoplanktons, zooplanktons, aquatic insects, benthic invertebrates, fish, and wildlife belonging to higher chordates) in the temporal and spatial scales, citing the case studies from the tropical riverine networks of the South West Bengal, India. Besides, different forms of stresses, both natural and human-mediated threats (deforestation, urbanization, modern agricultural practices, construction of dams, barrages, hydroelectric projects, etc.), on the riverine ecosystem have been dealt with in the light of prevailing socioeconomic/socio-political set ups. Sustainable eco-management practices with more stress on eco-restoration of eco-degraded riverine ecosystem have analyzed and properly explained.

Keywords Taxonomic hierarchy · Extinction · Eco-assessment · Eco-manipulation · Biological integrity · Ecological integrity · Aquatic biota · Riverine wildlife · Socioeconomic/socio-political interpretation · Sustainable eco-management

Life probably began around **3.5** billion years ago and has continued to the present. During this incredible span of history, literally millions, if not billions of life forms have evolved on the Earth and followed taxonomic hierarchy as species and subspecies, families, and genera which were risen to their fullest potential, fallen into decline and become extinct. All these events happened because of unsympathetic and demanding natural causes. Each species has had to cope with nature's demands and compete with other species in order to reproduce and perpetuate its own kind. Failing to accomplish this, it disappears and is gone forever. The powerful effects of competition among different species for food, water, light and also to have habitats for shelter and reproduction helped interacting species develop varied form of adaptive features which have neen reflected as species specific phenotypic expressions. Besides, competitive battles for survival result in some life forms evolving in ways that give them distinct advantages over others. Therefore, the existing life forms of the world are the successful survivors in this long, challenging, and compelling evolutionary process. All the forces that produced changes and extinctions were natural and happened by chance. However, once humans began to control and alter their surroundings, the impact on such intervention on the environment became very drastic and dramatic leading to the cause of the loss of species. For the first time in this long **3.5** billion-year adventure, people became a key part of the equation for determining the species survival.

Rivers being the reservoir of an array of biodiversity components in the flowing water ecosystem have been serving the sustenance of human beings since immoral by way of providing a lot of ecosystem services which have been threatened by human activities. Therefore, sustainable management of river ecosystem requires an integrated approach of involving different disciplines of science (physical, chemical, geological, biological, and mathematical) and also other branches of social science (sociology, economics, history, etc.) to pay more emphasis to restoration measures and also to reverse the ongoing environmental perturbation-mediated ecodegradation. This is thought to be achieved adhering to the pragmatic scientific principles of ecology for understanding the different pathways of complex interactions among different structural components of river ecosystem. Formulation of policies through adequate research and their implementation by governmental agencies seems pivotal to address the issues. Simultaneously, awareness at community levels and people's participation may also be essential to ensure sustained management programs for the effective maintenance and rejuvenation of surface and subsurface freshwater flows in and around river ecosystems as this ecologically potential and healthy freshwater ecosystems renders a wealth of goods and services for the society. Ecological capacity, therefore, varies from place to place, and higher levels of biological richness (speciosity) and bioproduction are most likely to occur in ecosystems with a long legacy of high spatial and temporal environmental heterogeneity.

10.1 Rivers and Human Beings

Different human activities such as changes in the land use patterns (deforestation, conversion of wetlands etc); modern agro-technological applications with the profuse uses of chemical fertilizers and persistent pesticides, large scale water abstraction for the irrigation support, construction of dams have ecodegraded most of the rivers of the world to a considerable extent. Reservoirs and hydroelectric projects and other water resource-based developments for promoting ecotourism and fisheries, etc. result in the alteration of all kind of natural ecological processes operating within river ecosystems which in turn considerably impose harmful effects on biological communities (Day, (1875-78; Dudgeon, 2000a, b), Chakraborty 2017, 2018; Karr 1999).

10.2 Eco-Assessment of Rivers and Biological Criteria

Although applications of biological criteria have become popular in the assessment of such ecological alterations across the world, definite research evidences on the relationships between ecosystem degradation and biological response are still very scanty. Stream habitats along with biotic assemblages provide the template as being a moving mosaic of environmental conditions upon which the ecodynamics of lotic ecosystems are designed and structured (Minshall 1984; Resh et al. 1988; Poff and Ward 1989; Townsend and Hildrew 1994; Richards et al. 1996) on which different population and communities of biota must either adapt or perish temporarily and spatially which continues until drastic environmental change, often from human activities, occurs and results in extinction (sensu Southwood 1977; Townsend and Hildrew 1994; Townsend et al. 1997). An assessment of river health and biotic integrity is possible only on establishing the links between the mode of adaptability of the organisms with their habitats and the factors which influence such adjustment.

10.2.1 Eco-Manipulation on Riverine Ecosystem: A Prerequisite for an Integrated Approach

Eco-manipulation of the river's biotic integrity has appeared to act as targets for the eco-management by altering the physical and chemical environment. Human demands on the world's available freshwater resources have been increased many fold during the last couple of centuries in tune with the increase of global population. Most of the earlier endeavors for the management of riverine flows with an eye to cater to the need of the human beings have been mostly relied on the water itself keeping aside the requirements of different water-dependent living organisms which have resulted evil ecological consequences. Therefore, the demand of the present mode of water management should focus on better management of freshwater flows in order to sustain these benefits towards freshwater biodiversity.

Different examples based on research studies from different corners of the globe during the past few decades can be cited to demonstrate the ways and means for meeting human needs of water alongside maintaining the required volume and timing of water flows with an objective of protecting the affected freshwater ecosystems. In such context, the compatible integration of the needs of human being and natural ecosystem should be taken care off by developing an integrated, holistic, and comprehensive approach in unraveling the mysteries of interrelationships among different structural components (living and nonliving), meteorological parameters, different eco-geo-biological processes, resilience manifestation in response to ongoing perturbations, and ecological consequences of inter connectivity of rivers with other adjoining ecosystems such as terrestrial, forests, floodplains, and wetlands.

Both ecological and society-driven biodiversity conservation become very much imperative in tune with the demands of the time. Increased dependence of human society on rivers for their all-round needs and benefits and the resultant developmental pressures have necessitated systematic, strategic, and integrated conservation planning and management of the rivers and their resource bases mostly adhering to the scientific ecological principle-based knowledge, in consonance with socioeconomic and ecological goals towards the conservation of river ecosystem. Such ecologically holistic and sustainable water management strategies and efforts are expected not only to meet the needs of the moments but also to keep the precious resources such as water and its dependent living and nonliving resources with all their goods and services for making them available for the future generation.

10.3 Consequences of Human Intervention on River Ecosystems and Biodiversity

Ecological changes after being brought about by human beings in the main river flows, river basins, and catchment landscapes by using or extracting environmental goods and services; river ecosystems have a certain natural capacity to maintain biota and produce biomass (Warren et al. 1979; Frisell et al. 1996), and that biodiversity and bioproduction are dynamic in time and space in relation to availability of resources (Benke et al. 1988). This is in contrast to the societal change which disrupts ecological quality or ecological integrity of landscapes without providing much scope for recovery (Blikie and Brookfield 1987; Schinberg and Gould 1994). However, biotic dynamics derive from natural variation in the environmental setting coupled with deviation from equilibrium conditions (logistic relationship between resources and bioproduction) rarely exist for very long because environmental changes are constantly reconfiguring resource availability.

Interventions of humans considerably reduce the potential of river ecosystems to sustain natural biodiversity by disrupting the dynamic interactive pathways of the river continuum as the site-specific biotic assemblages of rivers exhibit their own life history traits in tune with the changing ecological parameters unique for a particular river. Human interference with freshwater ecosystems has severely affected their natural physical characteristics and biological complexity, thus undermining their productivity and resilience. Strikingly similar erosion of biodiversity is underway in other parts of the world experiencing rapidly increasing economic growth (Dudgeon et al. 2006). For example, in tropical Asia where there is no legislation specifically regulating environmental protection or conservation to protect biodiversity, overexploitation of rivers has caused many fish populations to collapse (Dudgeon 2005). Enactment and enforcement of required legislation have been introduced throughout Asia to control water pollution, primarily because of the danger it poses to human health, and have been found to be effective against point source polluters, but have not shown desired results against the chemical and microbial pollutants coming out from non-point agricultural and domestic sources, respectively.

10.4 Different Ecological Stresses and Pollution on Riverine Ecosystem

Ecological stresses being either as natural events or human-induced activities refer to those undesirable disturbances having different frequency, duration, intensity, and location that bring changes to river ecosystems regardless of whether they act individually or in combination. Changes in the land-use patterns trigger a chain wise alterations of hydrological and hydraulic properties of the river, which in turn result changes in sediment transportation, deposition and thereby development of habitats, and ecological interactions among living and nonliving components. Understanding of the causes and effects of such resultant disturbances of variable of scales and time has appeared to prerequisite to undertake restoration of the function and structure of the streams and rivers ecosystem.

10.4.1 Natural Stresses

Climatic change, desertification, floods, hurricanes, tornadoes, erosion and sedimentation, fire, lightning, volcanic eruptions, earthquakes, landslides, temperature extremes, and drought are among the many natural events that have a negative impact on the structure and functions of a river ecosystem. The relative stability, resistance, and resilience of an ecosystem determine their response to a disturbance. Disturbances and their impacts on stream corridors. Soil and water environment and are manifested by different forms of erosions unable stream channels and impaired habitat.

Besides, tillage and soil compaction disrupt soil's capacity to partition and regulate the flow of water in the landscape, increase surface runoff, and decrease the water-holding capacity of soils. Application of pesticides and fertilizers (nitrogen-, phosphorus-, and potassium-based nutrients) in the agriculture through runoff can leach into groundwater and also flow into surface water of streams and rivers either dissolved or adsorbed to soil particles. Wastes and effluents coming from the animal-based food production industries and also even from the excretory discharges of human beings serve as the potential sources of chemical and bacterial contaminants to streams and rivers.

10.4.2 Land-Use Changes and Disturbances

Deforestation and removal of plants: deforestation not only enhances soil erosion but decreases the quantity of nutrients in the watershed, because of the reduction of decomposition of plant biomass. In addition, removal of the tree cover leads to short-term increase in nutrient release followed by long- term reduction in nutrient levels, disturb the quality, quantity and timing of stream flows increase the water temperature can during summer and decrease in winter. Several other land use changes (agriculture, urbanization, industrialization, etc.) cumulative or synergistically impose undesired cumulative effects on riverine ecosystems. Development of animal-based food production industries are also the sources of stresses on river ecosystem as those industries promote grazing pressures on the river basins on the ecosystem which modify sequences and rates of the succession by delaying or even stopping the transition from herbaceous to shrubs.

Corridors of rivers or streams offer ample scopes for foraging to livestocks which pose both positive and negative effects on the ecology on watersheds by increasing nutrients by the excretory products. In addition, swimming of livestocks in a stream can result in extensive physical disturbance and bacteriological contamination. Such positive and negative effects of grazing of domestic livestock can be used in any eco-restoration strategy. Moreover, higher nutrients that enriched both solid and liquid animal wastes coming out the animal production facilities act as potential contributor of chemical and bacterial non-point pollutants to the nearby streams or rivers.

Long-term monitoring of these natural environmental phenomena and ecological responses against them can develop repository of baseline information for undertaking effective management strategies for the rehabilitation, reclamation, and restoration of the affected environment. Restoration might not remove all disturbance factors; however, addressing one or two disturbance activities can dramatically reduce the impact of those remaining.

10.4.3 Erosion and Sedimentation: Direct Cause of Ecology Impairment

The dislodged sediments resulting from intensive soil erosion cause a strong stress on the aquatic bio-community and result low transparency, low-dissolved oxygen, higher sediment deposition forming coating over the bottom substrates, etc., all of which impact on fish and invertebrate communities.

Riparian vegetation, in general, displays resiliency despite the fact that a flood may have devastating destroying effects on the mature and stable a mature riparian forest, and the resultant conditions after the damage are usually like those of a nursery from where a new forest can be rejuvenated and established, to re-establish the riparian ecosystem to almost in its previous form mostly by deriving the support from the high biomass and deep-established root systems, which adapt to many such natural stresses (small and frequent droughts, floods, hurricanes, tornadoes, erosion and sedimentation, fire, lightning, volcanic eruptions, earthquakes, etc.)

10.4.4 Human-Induced Physical Disturbances

Human-induced physical disturbance and stresses undoubtedly have the greatest potential for altering the ecological structure and functions of stream corridors, causing impacts locally or at locations far removed from the site of origin. Different human activities as a part of ongoing urbanization coupled with industrialization such as flood control, road building and maintenance, irrigation for modern technology-based agricultural, urban encroachment, ecotourism, etc. can have dramatic effects on the geomorphology and hydrology of a watershed, river basins, floodplains, and the stream corridors .Chemically defined disturbances in the riverine ecosystems caused by the releasing, dumping, and introducing of both solid and liquid wastes through many anthropogenic activities including discharging of sewage and wastewater (acid mine drainage, heavy metals, detergents, microbial components, etc.), agriculture wastes (fertilizers, pesticides, etc.), and industrial (heavy metals, oils, hydrocarbons, etc.) into the rivers and streams. Besides, ecological disturbances resulting disruptions of natural community interactions such as predation, hybridization, etc. along with the development of diseases are caused mainly by the intentional or accidental.

10.4.5 Construction of Dams and Channels

Dams being the human-constructed barriers range in sizes from small temporary structures to huge multipurpose structures and can have profound and varying impacts such as deterioration of water quality, sediment load, deposition, disrupting normal movement of resident, and migratory organisms instream channels, which in turn affects food chains associated with stream ecological functions and prevailing ecological relationships.

Like dams, channelization disturbs the stream ecology, by damaging riffle and pool complexes needed by the aquatic biotic components in their different phases of the life cycle. The benefits of channelization towards controlling of floods and diversions are often offset by ecological losses resulting from increased stream velocities and reduced habitat diversity. Disturbed levees along rivers and diversion channels tend to accelerate soil erosion; reduce shading, temperature, and availability of nutrients; and decrease habitats for organisms on replacing and reducing trees and other riparian vegetation.

Water diversion from rivers mostly made to exploit the hydropower at low cost at many low dams impacts the stream ecology, depending on the timing and amount of water diverted, as well as the location, design, and operation of the diversion structure as river water is diverted through pipelines and tunnels to the hydropower plants, which are located at several tens of kilometers downstream.

10.4.6 Mining and Fragmentation of Habitats

Mining of sands, graves etc. from the river for building materials pose serious ecological stress in many rivers throughout India which in turn completely disturbed the benthic invertebrate community. Such mining causes loss of habitat for benthic bio-communities and loss of spawning ground for many fish species.

Lacking laws for controlling river sediment mining and attracted by great economic benefit, sediment mining has developed so quickly that almost all streams are stressed. Surface mining also causes stresses on the river ecosystem. Exploration, extraction, processing, and transportation of coal, minerals, and other materials have had and continue to have a profound effect on stream corridors. Many rivers ecosystems remain in a degraded condition as a result of mining activities. Such mining activity frequently resulted in total destruction of the stream corridor.

Fragmentation and isolation of habitats that are resulted out of such human activities result in the deterioration of the ecology and extinction of some species making fragmentation as a serious stress on the ecosystem and must be considered in ecological restoration of the river-lake complex system.

10.4.7 Human Interference and River Environment

Riverine environment is altered in respect of physical, chemical, and biological processes of river ecosystems which in turn result striking modification in the structure and function of biological communities mainly because of different water resource-based developmental projects and land-use changes. Although, it can be assumed without any doubt, biological criteria can throw light detailing the relationships between ecosystem degradation and biological response, but proper scientific proof remains lacking in most of such cases. A linear decline in the species richness of certain aquatic insects (mayfly under the order Ephemeroptera) with increases in the percentage of impervious surface area in the depressed lowland surrounding the streams of Puget Sound has been highlighted by Karr and Chu (1998). A more complex relationship between percentage of urbanization and habitat characters in respect of sediment texture (sands, gravel, etc.) of urban streams of the UK had been observed by Thoms (1987). A sigmoid relationship prevails in between the maturity of the urban area (nature of urban activities in respect of some attributes, **i.e.**, industrial vs. residential (the size of the urban area) in relation to the habitat characteristics within the river catchment. Detailed and transparent understandings of the relationships among the environmental variables of the rivers that affect biological condition have been strengthening the methods and tools for holistic river assessment of the health of rivers.

10.4.8 Urbanization, Recreation and Tourism

Urbanization coupled with the development of tourism can considerably put negative impacts on the ecological health of rivers as recreation and tourism industry depends on stream hydrology, soil type, vegetation cover, topography, and intensity of use riparian vegetation and soil structure. Hydrology, soil type, vegetation cover, topography, and intensity of use of river ecosystem have been impacted considerably by the recreation and tourism industry. Various forms of conveyances and vehicular traffic associated with recreational activities damage riparian vegetation, increase erosion, modify soil structure by increasing soil compaction, reduce infiltration, and result habitat reduction by increasing sediment loading to the stream (Cole and Marion 1988). Rapid pace of urbanization in and around river basins and nearby watersheds, causing dramatic changes of land uses, poses cumulative or synergistic impacts on the environment and offers special challenges for stream ecological management as rivers and streams flowing in urban watersheds display some specified characteristics fundamentally different from other lotic water bodies surrounded by agriculture fields or forests.

Impervious cover directly impose ecological problems on urban streams by dramatically increasing surface runoff during storm events which influence the water balance and accelerate the process of different forms of erosion sheet erosion, rill erosion, and gully erosion, reduced infiltration, increased upland surface runoff and transport of contaminants, increased bank erosion, unstable stream channels, and impaired habitat for a water under influence of urbanization. Tillage and soil compaction directly also interfere with the soil's capacity to partition and regulate the flow of water restricting the movement of water into the subsurface in the landscape, increase surface runoff, and decrease the water-holding capacity of soils. Agriculture-mediated disturbance of soil generates runoff loaded with sediment particles, chemical pesticides, and fertilizers (mainly nitrogen, phosphorous, and potassium) as non-point pollution either dissolved or adsorbed to soil particles which on reaching higher concentration leach into groundwater or flow in surface water to stream corridors.

10.4.9 Pollution of Rivers: Different Pollutants and Sources

The undesirable changes in the functioning of river ecosystem take place by an array of pollutants which may be of solids (sand, gravel, soil, ashes, cinders, clinkers; shoots, mine, quarry, sludge of sewage, decaying vegetable, and residues from garbage; carcases of animals, rubber, wood, paraffin wax, gelatine, straw, paper or paper pulp, even animal husbandary and bakery products, etc.) or liquid mainly discharged through domestic sewage and industrial wastes into rivers which may contain dissolved or suspended materials and different forms of dissolved gases.

Point source of pollution from industry (heavy metals, hydrocarbons, oils, etc.) and non-point diffuse pollution from agriculture (pesticides, and fertilizers) and domestic activities (detergents, sewage microbes and nutrients) have the potential to disturb natural chemical cycles in streams and, thus, to deteriorate water quality and impact the ecosystem.

Sewage discharge from the city causes pollution of the river water and also triggers blooming of unwanted phytoplankton and macrophytes, which in turn drastically reduce the dissolved oxygen etc. as a consequence of cultural eutrophication. Toxic runoff not only result mass mortality of vegetation but also cause a shift to species more tolerant of polluted conditions. Acid mine drainage affects the habitat for bottom dwelling and feeding organisms by coating stream bottoms with iron precipitates and thereby eliminates species from the bottoms, the suitable places for the survival of eggs and juveniles of many aquatic faunal components. Polluted bottom sediments and flowing water result an unfavorable and hostile ecological condition for the fish to hatch their eggs.

Agricultural wastes, persistent chemicals (non-point pollutants) after being attached to sediments, increase their concentration through biotransformation and bio-magnification processes. Introduction of exotic species and ecological impacts biologically defined disturbances caused by the natural interactions and activities of biological organisms which are of are twofold:

1. Occur within species (competition, cannibalism, etc.).
2. Happen among species (competition, predation, etc.).

These act as determinants of population size and community organization in many ecosystems. Exotic species of flora and fauna after being introduced result widespread, intense, and continuous stress on native biological communities, which even lead to cause the extinction of native organisms. Introduction of bio-invasive fauna having higher potentiality of reproduction causes biological problems in the ecosystem by preying on numerous native, residential, or indigenous faunal components. Altering the structure of natural plant communities alters the natural infiltration and movement of water and thereby results modification in the timing and magnitude of runoff events which synergistically accelerate and aggravate the economical and ecological conditions. Compared to faunal species, introduction of floral species is quicker and more intensive because humans pay less attention to the negative impacts of the introduction.

The introduction of exotic species, whether intentional or not, can cause disruptions such as hybridization and the introduction of diseases. Exotic or alien species pose serious competitive challenge to native species for getting space along with other life supporting attributes such as moisture, nutrients, sunlight, etc. and adversely influence establishment rates for new seeds and saplings of plants, larvae, and juveniles of animals which are in need of settlements, colonization, and propagation.

Out of so many, striking example may be cited with golden mussel (*Limnoperna fortunei*) which acts as an invasive filter species of macro-invertebrate, which after being originated from China has so been spread over to various regions of the world, including Japan, Australia, Argentina, Thailand, India, Brazil, and Europe (Darrigran et al. 2003). These gastropods possess unprimitive byssus threads, which enable them not only to anchor the solid structures human constructed by human beings for water transfer as tunnels and pipelines, cemented tunnels, water vessels, etc.

Biology of this golden mussels includes high reproduction rate, power of settlements in the alien habitats, (water diversion tunnels, cooling pipelines, pumps, and gate slots,), and ability for rapid colonization, ultimately leading to damage to these facilities.

10.5 River Management: Physical and Biological Factors

10.5.1 The River Continuum Concept

The river-continuum concept, a holistic approach towards riverine flows and their variability from the head water to downstream along with highlighting various forms interactive ecological processes (nutrients availability and utilization, energy flows through trophic interactions, orderly processing of organic materials by the biotic community through eco- biological interactions) advocates that forested river systems having a longitudinal structure have been developed a result from a gradient of physical forces that produce a continuum of morphological and hydrological features from the headwaters to the mouth. and experience predictable changes along the length of the river- (Vannote et al. 1980).

10.5.1.1 Sources of Energy and Roles of Biota

The river continuum concept advocates about the threefold sources of energy required for biological production:

1. Allochthonous inputs of organic matters from terrestrial vegetation at upstream
2. Increased primary production within the stream (autochthonous production), at the wide riverine tract at the middle stream
3. Transportation of the food particles (coarse organic particulate materials to ultrafine particulate organic matters from) upstream

These three energy sources vary along the river continuum through interactions of biological communities with the physical and biological environmental parameters in order to maintain dynamic equilibrium which helps to predict on the variability of the environment and the source of energy for biological production (Vannote et al. 1980; Ward and Stanford 1983a).

10.5.1.1.1 Roles of Functional Feeding Groups (FFG) in RCC: Exchange of Nutrients and Primary Production

The River Continuum Concept (**RCC**) explains the complexities of the interactions among biotic and abiotic components of running water ecosystems emphasizing on **Functional Feeding Groups** (**FFG**), which has improved the existing understanding of the ways and means for the application of knowledge base in respect of eco-biology and taxonomic descriptions of aquatic non-chordates as biological indicators for the eco-assessment of ecological changes of rivers and streams (Vannote et al. 1980).

Organic matter of living organisms trigger energy fluxes within the river and between the river which experience ecological changes along a physical gradients throughout its length and also receive energy inputs in the form of leaf litter falling into the river; biofilms (assemblages and colonies of algae, fungi, and bacteria) settled mostly on hard structures, dissolved organic matter (**DOM**) in the water column. Generally, the plants and animals in low-order streams and tributaries (heterotrophic with **P/R ratio < 1**) serve as the primary source of organic matter (allochthonous materials) and govern fluxes of energy to sustain all geo-ecological processes (Steen 1971; Vannote et al. 1980; Allan 1987; Harding et al. 1998; Graca 2001).

Five functional feeding groups can be classified: shredders, gathering collectors, filtering collectors, scrapers (grazers), and predators which are encountered in their preferred ecozones delimitated by different ecological processes of riverine flows from the upstream to downtream.

10.5.1.1.1.1 Shredders

Shredding invertebrates (amphipods, Ephemeroptera (mayflies), Plecoptera (stoneflies), Diptera (flies and midges), and Trichoptera (caddisflies) representing an important group of organisms along a river continuum which set off the nutrient cycling processes within a stream (Merritt and Cummings 1996; Graca 2001) and prefer to inhabit in low-order streams, that is, mostly heterotrophic (**P/R < 1**) receiving allochthonous food materials from the adjacent riparian vegetation which are shredded and broken down by the specially designed cutting mouthparts of shredderers, and they thereafter utilize coarse particulate organic matter (**CPOM**) as their food and thereby control the nutrient cycling processes along a river continuum within a stream (Vannote et al. 1980; Allan 1987). These animals prefer to inhabit at upstream (Merritt and Cummings 1996; Graca 2001 Vannote et al. 1980; Allan 1987). In addition, low-order streams tend to be heavily shaded and are characterized by low primary production, because the water column is generally depleted in dissolved inorganic nutrients (**DIN**) such as dissolved inorganic nitrogen and phosphorous, which are the nutrients necessary for algal tissue formation. After entering the stream, **CPOM** is partially consumed and processed by shredders, which results in the breakdown of **CPOM** into smaller particles such as **FPOM** and **DOM** (Allan 1987).

The mouthparts of **shredding invertebrates** have been developed to **cut and shred apart CPOM** to transform the **CPOM** to **fine particulate organic matter** (**FPOM**) (Merritt and Cummings 1996; Allan 1987), which in turn are incorporated within the organic nutrients into the food web (Graca 2001). Organic matter resources not utilized in the upstream reaches of a river will be transported downstream, where they can be utilized by collectors and filter feeders (Vannote et al. 1980). The enhancement of breakdown of organic materials in the streams are made by shredding taxa and thereby making food resources available in the form of **FPOM** before the emergence and growth of collecting taxa. The combined actions of both have a close and important role in the processing of allochthonous particulate materials.

10.5.1.1.1.2 Gathering Collectors

Collectors contribute to the further decomposition of FPOM by collecting and feeding on organic matter that settles out of the water column into the stream bed, which is generally smaller than 1 mm in size (Merritt and Cummings 1996). The particulate coarse organic matters produced by the shredders carried to the further downstream where they are further processed by the collectors [Ephemeroptera (mayflies), Plecoptera (stoneflies), Diptera (flies and midges), nematodes, oligochaetes, crustaceans and gastropods)] which consume **FPOM** and **ultrafine particulate organic matter** (**UFPOM**) under heterotrophic conditions still further downstream where the river widens and too deep for the benthic plants to grow but with higher primary productivity (Vannote et al. 1980; Allan 1987; Graca 2001). **The mouthparts of gathering collectors function much like a broom,** though which they can sweep and collect **FPOM** and **UFPOM** from the stream substrate. **Gathering collectors** depend on the organisms associated with **FPOM**, such as fungi and bacteria, in order to derive nutritional value from the food that they consume, and will preferentially **feed on FPOM** that has been colonized by biofilms (Vannote et al. 1980; Allan 1987). By being consumed, **FPOM** and **DOM** undergo further breakdown, which makes available the necessary nutrients for primary production (Vannote et al. 1980). Incorporation of organic matter into the food web increases downstream (Rosi-Marshall and Wallace 2002) and is accompanied by a shift in the type of organic matter consumed (Vannote et al. 1980; Rosi-Marshall and Wallace 2002).

The middle reaches of a river are characterized by a decrease in allochthonous material and an increase in the production of autochthonous organic matter such as aquatic macrophytes, periphyton, and biofilms (Vannote et al. 1980; Allan 1987). The structures of invertebrate communities, especially the grazers and gatherers are changed in the middle reaches of rivers because of changes in the nature of the food resources as production of algal mats and periphyton are increased in this ecozone of river with the increase of nutrients necessary for algal production are available in the water column (Vannote et al. 1980; Allan 1987).

10.5.1.1.1.3 Scrapers (Grazers)

Scrapers or grazing invertebrates [(Ephemeroptera (mayflies); gastropods, Lepidoptera, Coleoptera are the primary consumers of benthic autotrophs)] feed on attached algal communities (periphyton) and biofilms (Vannote et al. 1980; Allan 1987; Graca 2001). Their mouthparts, which act **much like chisels, are** specially adapted to remove periphyton and biofilms of less than 1 mm in size attached to rocks, woody debris, and aquatic macrophytes (Merritt and Cummings 1996). **Scraping invertebrates** are restricted their distribution within high-quality habitats of midstream reaches that are provided by periphyton and algal mats which in turn render protection them from the attacks of the predators of large numbers of invertebrates (Rosi-Marshall and Wallace 2002). The largest reaches of a river are characterized by slow flows and channels that are wide and deep with silty substrates that are unsuitable for the benthic macro-invertebrate to grow (Allan 1987) and also limit the algal production due to water turbidity and depth (Vannote et al. 1980). Higher production of periphyton and more occurrences of biofilms and all of such conditions enable them to become the most abundant faunal group in middle stream reaches (Vannote et al. 1980). The decrease in algal production was due to changes in algal species composition, which respond to the presence or absence of grazing invertebrates. In the presence **of grazers,** highly productive filamentous algal species were replaced by less productive prostrate algal species. On reaching the high-order streams and rivers, organic matter resources are converted as **FPOM** and **UFPOM** which enable the invertebrate community mostly composed of planktonic invertebrates to live suspended in the water column and planktonic and benthic invertebrates which act as predators and filtering collectors, respectively (Vannote et al. 1980).

10.5.1.1.1.4 Filtering Collectors

The name of this functional feeding group states that filtering collectors as dominant feeders in high-order streams consume organic matter suspended in the water column along with abundant phytoplankton (Merritt and Cummings 1996; Graca 2001). Suspended organic matter includes living phytoplankton and their body parts, **FPOM and UFPOM** (Allan 1987). **Filtering feeders** may be benthic or planktonic. **Planktonic filter feeders** include taxa such as rotifers, copepods, cladocerans, and Diptera larva (Allan 1987). **Benthic filter feeders** include many species of caddisflies, whom spin nets on the stream substrate to collect organic matter from the water column (Merritt and Cummings 1996). **Filtering mechanisms** in this group of organisms can vary greatly. For example, cladocerans pump water through their abdomen, which contains a filtering apparatus that collects suspended particulate matter. Other organisms, such as Simuliidae dipterans (black fly larvae), possess large fans in their mouth, which they use to collect the suspended particulate matter from the water column (Merritt and Cummings 1996).

10.5.1.1.1.5 Predators

Common predatory taxa including members of the order Diptera (flies and midges), Coleoptera (beetles), Trichoptera (caddisflies), Plecoptera (stoneflies), Megaloptera (dobsonflies), and order Odonata (dragonflies and damselflies) (Merritt and Cummings 1996b) are organisms that derive their metabolic energy from living animal tissue (Merritt and Cummings 1996; Graca 2001). **Predators enjoy different modes of feeding in a variety of ways**. Some predators consume their prey whole or in pieces, but some possessing the piercing mouthparts are able to predate by extract nutrients from their preys without chewing, instead shredding (Allan 1987; Merritt and Cummings 1996). Invertebrate predators often compete for the same food resources as with young fish. For example, damselfly larvae and fish may compete for chironomid (midge) larvae (Allan 1987). Therefore the absence of one competing predator may enhance the growth and increase the population size of another competitor.

10.5.2 Flood Pulse Concept and Effects on Biodiversity

The main thrust of the flood pulse concept is the driving of the annual cycles of river processes by the flood pulse over a large and diverse spatial domain which in turn result (Junk et al. 1989). Channel morphologies along with their ecology (nutrients input and biodiversity) are determined by the annual cycles of flood which fill channels with inorganic and organic materials eroded laterally and vertically at upstream locations, thereby producing a continuum of instream structures (pools, runs, riffles, gravel bars, avulsion channels, islands, debris jams) and lateral floodplain terraces having different sizes and shapes.

The subsequent ecological responses of river basins in respect of biochemical cycles, particularly for organic carbon, size, dynamics, and transport, are documented by (Junk et al. 1989; Junk and Wantzen 2004; Richey et al. 1991; McClain 2002; Bunn and Arthington 2002; Ward and Stanford, 1983b, c) Welcomme and Halls 2004). Local geomorphologies of the channels at specific site after being structured by large but infrequent floods may persist with the same configuration for longtime periods (quasi-equilibrium) until the next big flood. Simultaneously, interim flow dynamics in slow, gradual, and steady process restructure instream geo-ecological structures (Schummand Lichty 1956).

10.6 Functional Food Webs and Energy Flows of Streams and Rivers

Macro-invertebrate being an essential biodiversity components in the rivers takes active roles on nutrient cycling determining the proportionate distribution of all the fractional components of nutrients as evident from the research studies of Rosi-Marshall and Wallace (2002) who observed a decline of **CPOM** which decreased from being **58%** of the total food consumed in the low-order streams, to only about 6% of the total food consumed in high-order streams. Besides, they also found that consumption of **FPOM** increased from 18% in low-order streams to **64%** in high-order streams, whereas the consumption of organic detritus derived from the animal sources showed an increase of **27%** at downstream from 3% at upstream. In addition, stream invertebrates regardless of their **functional feeding group** are being preyed by one group of animal or another (Allan 1987). River geomorphology and physicochemistry play an important role in determining longitudinal variation in food web properties such as fish species richness and connectance. Several fundamental insights into the ecology of flowing waters suggest exploring longitudinal changes in food webs along river networks (Vannote et al. 1980).

First, the extent upstream processes in rivers consistently determine downstream processes, which bring forth predictable changes of food web structure along river networks longitudinally from headwater streams to river mouths.

Second, the consistent changes of physicochemical variables (temperature, nutrients, etc.) biotic variables (primary productivity, community composition, etc.), and physiographic variation (geomorphology, hydrology, current, velocity, etc.) along river networks cause predictable food web patterns (Vannote et al. 1980; Minshall et al. 1983).

Finally, strong anthropogenic disturbances through the drastic land-use effects significantly alter the biota of streams and rivers deviations from predictable changes in food-web structure (Allan and Flecker 1993; Johnson et al. 1995).

Comparisons of among varied form of changes in the food web structure across different regions of rivers illuminate the influences of regional and local ecological conditions on food webs and thereby provide a scientifically powerful alternative on the modes of disruption of food webs by the series changes in the land uses in the past. Physiography exhibiting regional boundaries affects the surrounding landforms, habitat quality, disturbance patterns, and upstream–downstream linkages (Swanson et al. 1988) which in turn influence the rivers channels and drainage systems to support the abundances and distribution of distinctive fish faunas (Hocutt and Wiley 1986; Jenkins and Burkhead 1994). Lower trophic taxa of the river food web includes primary producers (phytoplankton, macrophytes), secondary producers (zooplankton, phytophagus macro-invertebrates), consumers, omnivores and scavengers (aquatic insects, gastropods, amphibians, crustaceans, bivalves, worms, leeches, etc.), and detritus associated with **POM**, **CPOM**, decomposing organic matter, etc. and fish species belonging to each food web based on their feeding preferences coupled with foraging abilities fish species ranges in (Nelson and Paetz 1992).

Mostly, the aquatic food webs are constructed by employing several key assumptions.

First, presence and absence of data for biotic components including fish species are aggregated in accordance with physiographic region and river basin.
Second, all taxa are assumed to be present regardless of seasonal or temporal bias.
Third, all feeding links present across all ontogenetic stages are included for each fish species.

In the realm of river ecology, the River Continuum Concept (Vannote et al. 1980) embracing longitudinal patterns and processes after being blended with nutrient spiraling (Newbold et al. 1981) ones have long been developed as unifying concepts. However, a number of human made developments such construction of dams, barrages, irrigation channels, hydroelectric projects, etc. cause fragmentation and thereby discontinuities within this longitudinal continuum (Ward and Stanford 1983a) which tend to impose pressure to reset to biotic communities along gradients.

In the light of ever-growing human needs and demands on the world's available freshwater supplies in tune of the global population explosion during previous two centuries especially after the Second World War, river managers undertook several endeavors to manage river water along with conservation of freshwater species and ecosystems in order to combat the tragic ecological consequences. River ecosystems with sound ecological health contribute a lot of ecological goods and services for the society, but the perception of human civilization should be better managed and oriented to sustain these benefits and freshwater biodiversity. An eco-management framework for ecologically sustainable water management alongside meeting the human needs for water by storing and diverting water for sustaining or restoring the ecological integrity of affected river ecosystems following the undermentioned steps.

1. An initial quantified estimates covering key features of river flows are necessary to sustain native species and natural ecosystem functions.
2. Proper accounting for both current and future requirement of human uses of water that facilitate development of a computerized hydrologic simulation model to be used for an understanding of human-induced alterations to river flow regimes.
3. Assessing incompatibilities between human and ecosystem needs with particular attention to their spatial and temporal character;
4. Searching for solutions to resolve incompatibilities by undertaking collaborative interdisciplinary ventures.
5. Experimental efforts through trial and errors are required to be conducted for water management for resolving critical uncertainties towards integrating human and ecosystem needs.
6. Designing and executing an adaptive management program to facilitate ecologically sustainable water management for the long term.

Since the middle of the last century research, emphasis was directed towards describing and measuring biological production and energy flow within the rivers and streams in relation to the changing hydrodynamics and geomorphology. However, during the previous few decades, holistic approach combining the physical and biological concepts of stream organization and viewing lotic systems as interdependent combinations of the aquatic and terrestrial landscapes have been become very popular. Energy flows depending on the inputs from energy sources through food webs result biological production in large rivers which are reflected by the eco-geo-biological features of habitats. The importance of energy source in the form of organic matter to ensure riverine productivity relies on the quality of the organic matter instead of its quantity of supply (Maltby 1992; Thorp and Delong 1994). Transportations of organic matter to long distances tends are thought to be refractory in nature having fewer attached microbes and thereby display less efficiency to contribute to secondary production than the locally derived (autochthonous sources) nutrients from the floodplain or (Naiman 1983; Thorp and Delong 1994).

The quality as well as quantity of the production of autochthonous nutrients are found to be dependent on the intensity and duration of flooding, ecological condition of floodplain, extent of distribution and biomass of riparian vegetation, amount, intensity, and scopes for availability of sunlight of light, and such nutrients play critical roles in determining the energy flows, primary, and secondary production, providing avenues for the growth, and flourishing of life such as phytoplankton, zooplankton, benthos, nektons, macrophytes, aquatic grasses, and plants (Fry and Sherr 1984). However, sources of energy exhibit seasonal and annual changes or annually, triggering the changes in energy and biological productivity flows over time.

Similarly, enhancement of productivity takes place by flooding, but variability in the flood cycle, coinciding with appropriate temperatures and rates of inundation, acts as critical factor in determining productivity levels (Bayley). Functional classification of rivers biodiversity components. Macro-invertebrates, being essential biodiversity components in the rivers take active roles on nutrient cycling determining the proportionate distribution of all the fractional components of nutrients as evident from the research studies of, Rosi-Marshall and Wallace (2002) who observed a decline of consumed **CPOM** as consumed food from **58%** in the low-order streams, to only about **6%** of CPOM as consumed food the in high-order streams.

Besides, they also found that consumption of **FPOM** increased from **18%** in low-order streams to **64%** in high-order streams, whereas the consumption of organic detritus derived from the animal sources showed an increase of **27%** at downstream from **3%** at upstream. In addition, stream invertebrates regardless of their functional feeding group are being preyed by one group of animal or another (Allan 1987).

10.7 Food Web and Geomorphology

The geomorphology and physicochemistry of river by virtue of their decisive roles determine the longitudinal variation of food web properties such as fish species richness and connectance of the river ecosystems (Vannote et al. 1980).

Twofold influences are found to operate on food web dynamics of riverine ecosystem: **first,** the extent upstream processes in rivers consistently determine downstream processes, which bring forth predictable changes of food web structure along river networks longitudinally from headwater streams to river mouths. **Second**, the consistent changes of physicochemical variables (temperature, nutrients, etc.), biotic variables (primary productivity, community composition, etc.), and physiographic variation (geomorphology, hydrology, current, velocity, etc.) along river networks cause predictable food web patterns (Vannote et al. 1980; Minshall et al. 1983).

Finally, strong anthropogenic disturbances through the drastic land-use effects significantly disrupt the basic operating fabrics of food chains and food web dynamics of rivers' biotic community which deviate markedly from the predictable changes in food web structure (Allan and Flecker 1993; Johnson et al. 1995). Comparisons of how changing of food web structure across different regions of rivers illuminate regional and local influences on food webs providing a scientifically powerful alternative of the modes of disruption of food webs by land use and history.

Physiography-exhibiting regional boundaries influence and structure the adjoining landforms, disturbance patterns, upstream–downstream linkages, and habitat quality (Swanson et al. 1988) which in turn influence the rivers channels and drainage systems to support the abundances and distribution of distinctive fish faunas (Hocutt and Wiley 1986; Jenkins and Burkhead 1994). Lower trophic taxa of the river food web includes primary producers (phytoplankton, macrophytes), secondary producers (zooplankton, phytophagus macro-invertebrates), consumers, omnivores and scavengers (aquatic insects, gastropods, amphibians, crustaceans, bivalves, worms, leeches,), and detritus associated with **POM, CPOM**, decomposing organic matter, etc. and fish species belonging to each food web based on their feeding preferences coupled with foraging abilities fish species ranges in (Nelson and Paetz 1992). Mostly, the aquatic food webs are constructed by employing several key assumptions. **First**, presence and absence of data for biotic components including fish species are aggregated in accordance with physiographic region and river basin. **Second**, all taxa are assumed to be present regardless of seasonal or temporal bias. **Third**, all feeding links having different ontogenetic stages are considered for each fish species. In the realm of river ecology, the **River Continuum Concept** (Vannote et al. 1980) embracing longitudinal patterns and processes after being blended with nutrient spiraling (Newbold et al. 1981)ones have long been developed as unifying concepts. However, a number of human made developments such construction of dams, barrages, irrigation channels, hydroelectric projects, etc. cause fragmentation and thereby discontinuities within this longitudinal continuum (Ward and Stanford 1983a) which tend to impose pressure to reset to biotic communities along gradients. In the light of ever-growing human needs and demands on the world's available freshwater supplies in tune of the global population explosion during previous two centuries especially after the Second World War, river managers undertook several endeavors to manage river water along with conservation of freshwater species and ecosystems in order to combat the tragic ecological consequences.

10.8 Ecosystem Services and Goods

River ecosystems with sound ecological health contribute a lot of ecological goods and services for the society, but the perception of human civilization should be better managed and oriented to sustain all these biodiversity-mediated benefits. An eco-management framework for ecologically sustainable water management alongside meeting the optimum needs of water for human beings and also restoring the ecological integrity of affected river ecosystems by devising proper methods for storing and diverting water include under mentioned steps.

1. An initial quantified estimates covering key features of river flows have appeared to be prerequisite to safeguard the native species and natural ecosystem functions.
2. Proper accounting for both current and future requirements of water for human uses has to be computed with hydrologic simulation model that facilitate development of a an understanding of the prospective alterations to river flow regimes by the anthropogenic activities.
3. Assessments of the existing incompatibilities between human needs and ecosystem potentials emphasizing spatial and temporal characters are to be made.
4. Efforts are always to be undertaken for resolving incompatibilities through developing collaborative interdisciplinary ventures.
5. Experimental efforts through trial and errors are required to be conducted for water management for resolving critical uncertainties towards integrating needs of the human with the requirements of the ecosystem.
6. Designing and executing an adaptive management program in order to ensure achieving an ecologically sustainable water management for the long term.

10.9 Pulsing Hydrology and Top-Down Control in Tropical River: Prediction of Ecodynamics

Riverine flows from the headwater to extreme downstream at the confluence with sea experience an array of interactive influences from the variable hydrological and biophysical factors that influence primary production and population dynamics of several forms of life (plankton, benthos, periphytons, nekton, etc.) after sustaining relative influence of bottom-up and top-down processes in trophic networks.

River ecosystems like all other natural ecosystems exhibit pulsing of abiotic factors (temperature, **pH**, dissolved oxygen (**D.O.**), precipitation, solar radiation, etc.) and biotic components (producers, consumers, decomposers, population outbreaks, mass migrations, etc.) and are in turn is regulated by the pulsing effects in temporal and spatial scales. All of those ecological variables synergistically influence ecological interactions and ecosystem processes (Yang et al. 2008, 2010). This has been evident by studying the changes in trophic interactions across the land–water interface, i.e., the lateral dimension, during the rise and fall of flood pulses due to the variation of nutrients, detritus, and biotic resources imported from the surrounding riparian zones and watersheds along longitudinal fluvial gradients, on the food webs of lotic ecosystems (Woodward and Hildrew 2002). Greater flow pulses have been found to impart direct controlling effects on establishing and shaping the structure of specified benthic faunal and algal community dislodging and displacing other aquatic organisms; bringing changes in the patterns of suspension, deposition, and redistribution of sediments; and ultimately modifying availability of key resources (Power et al. 2008).

Changing patterns of stream flow regulate the trend of influence of top-down on animals in procuring basal resources (Power 1990, 1992; Basaguren et al. 1996; Pringle and Hamazaki 1997; Power et al. 2008). In such context, baseline research information of causal relationships between hydrology, physicochemical variables, and biotic components have appeared to through light on successful prediction of ecological dynamics within fluvial systems. Most tropical rivers experiencing seasonality in respect of temperature and precipitation tend to compose the ecological uniqueness of **Intertropical Convergence Zone** where the flood pulses are not only predictable but induce gradual changes in concentrations of nutrients, the prime architect of causing higher densities of aquatic organisms including fish.

This has also been observed that fishes feeding on benthic fauna can regulate abundance of particulate organic matters present on hard substrates (Winemiller et al. 2006). The higher intensity of such top-down effect coincides with the low-water phase loaded with higher concentrations of dissolved inorganic nutrients and ecosystem productivity resulting higher fish densities (Cotner et al. 2006; Montoya et al. 2006; Roelke et al. 2006).

Considering all of these observations, it can be hypothesized that the relative magnitude of top-down control on aquatic basal resources should follow a gradual transition in accordance with cyclical changes in water level and densities of fishes and other aquatic consumers. During the descending phase of the flood pulse, fish densities are found to exhibit an increasing trend which is supposed to be due to disturbed habitat conditions with an influx of migratory detritivorous fish which are expected to play an especially important ecological role because of their high abundance during the dry season.

10.10 Rivers and Floodplains: Ecology and Biodiversity

Naturally flowing floodplain rivers are among the more productive and dynamic ecosystems of the world with enormous spatial and temporal complexity. Determine The distribution patterns of channels, both fresh water and saline lakes, reaches, back swamps, marshes, lagoons, overflows and tributaries that make up the floodplains on receiving water from the river flows (Ward 1998). The flow regime of a river, and its connections to floodplain wetlands, governs biotic responses, channel formation, sediment transfer, influx of organic nutrients, and organic matter derived from the decomposition of leaf litter of aquatic macrophytes (Briggs et al. 1985; Outridge 1988; Junk et al. 1989; Walker et al. 1995).

Entry of riverine flows loaded with different biotic and abiotic components triggers the setting of dynamic ecological processes and trophic interactions involving a wide range of floral and faunal species. Organic matter provides food for microbes (Outridge 1988; Boon et al. 1996), phytoplanktons and benthic algae, zooplankton, and different forms of benthic invertebrates which are categorized as collectors, shredders, scrapers, and filter feeders (Lake 1995). Zooplankton on emerging from the dormant eggs of the newly flooded floodplains (Boulton and Lloyd 1992), start grazing on microbes (Boon and Shiel 1990) and then switched over to consume other kind of food materials.

Colonizers, such as fish larvae from the river, arrive although initial high levels of tannins and low oxygen may limit habitat suitability (Gehrke et al. 1993). Abundant insects with rapid generation times also follow the flood sequence (Maher and Carpenter 1984; Maher 1984), sometimes months after flooding (Crome and Carpenter 1988). Aquatic macrophytes, invertebrates, frogs, and fish provide food for water birds (Kingsford and Porter 1994), which colonize in the wetlands and developed the practice of breed later (Crome 1986).

10.11 Floodplains vs Dams

Partial or complete, temporary or permanent cut-off of the water supply to floodplain wetlands can be achieved by filling dams, diverting flows upstream, or river management on the river or floodplain. Dams cause hindrance to the flows to floodplains by capturing the flood pulse, reducing the frequency and volume of flows to them, and then diverting the water to the main river channel. A cumulative synergy between the construction of dams and diversions also affect the flow regime (Walker 1985), shifting flooding from a spring to summer pattern on southern rivers (Maheshwari et al. 1995) and affecting temperature (Walker 1985), channel stability (Thoms and Walker 1993; Walker and Thoms 1993), and salinity (Walker and Thoms 1993). Although harmful effects of dams to riverine fauna and flora (Bell et al. 1980; Harris 1984; Walker 1985; Chessman et al. 1987; Doeg et al. 1987; Marchant 1989; Walker and Thoms 1993) but ecological impacts on floodplain wetlands are poorly understood. Loss of connectivity to the river changes aquatic systems to terrestrial ecosystems. Aquatic plants, sedentary animals (burrowing frogs; aquatic invertebrates), and microbes adapted to unpredictable flood events eventually die and are replaced by terrestrial vegetation.

Regulation reduces the availability of floodplain habitats which have widespread impacts for native fish both juveniles and adults and water birds (Geddes and Puckridge 1989; Gehrke et al. 1995, 1999; Harris and Gehrke 1997). Reduced flooding may have an impact colonial water birds (ibis, egrets and herons) breeding on only a few large floodplain (Kingsford and Johnson 1999). Three areas exist for urgent ecological research on floodplain wetlands. **First,** long-term ecological impacts of water resource development on biota, ecological processes, and hydrology of floodplain wetlands need to be investigated. This will allow the ecological costs of proposed water resource developments to be defined.

Second, hypotheses about relationships between hydrology and floodplain ecology (states and processes) need to be tested, using floods as landscape-scale experiments (Sparks et al. 1990; Power et al. 1996).

10.12 Conservation and Management of River Ecosystem

Ecologically sustainable water management aims at ensuring safeguarding the ecological integrity by way of maintaining the steady-state ecosystem functioning alongside providing the necessary goods and services of the natural freshwater ecosystems. Besides, the conceptual basis for the sustainable conservation and management strategies for large rivers to sustain biodiversity and bioproduction is guided by a number of intertwined ecological principles. However, no single theory encompasses the myriad of biophysical interactions and responses to natural and human disturbances as the all the rivers of the world are not same. However, fundamental principles do apply; many conservation and restoration efforts which too often fail because plans and actions overlook ecological fundamentals.

Unregulated rivers existing as geo-hydraulic continua from the point of their origin to the extreme culmination point at the downstream near the oceans reconfigure the physical form of the interconnected flow pathways by dissipating the energy of flowing water and primarily by the process of cut and fill alluviation (Leopold et al. 1964), whereas the networks of surface and groundwater flow paths drain catchment landscapes (Gibert et al. 1990). Inorganic and organic materials after being eroded from the upstream get deposited in the downstream which are associated with a number of ecological processes within the river:

1. Long- and short-term flow dynamics
2. The resistivity of geological formations to erosion and dissolution
3. Instream retention structures (eddies, wood debris)
4. The geometry of the catchment

10.13 River Management and Restoration: Past vs Present

The restoration is fundamentally about allowing rivers or stream ecosystems to re-express their eco-potentiality to ensure ecologically healthy habitat development overcoming the ongoing developmental constraints along with the monitoring of the biotic responses to habitat development. The pervasive roles of human being in the process of controlling and dominating the ecosystem disturb the habitats and biotic communities which in turn cause a decline of the productive capacity of biotic resources (Warren and Liss 1980; Frissell et al. 1993). Owing to pervasive dominance of human beings on river ecosystems through different centuries, decades and years have resulted, continual perturbation leading to perturbation of the natural ecological settings of the habitats of florsa and fauna. The cumulative effects of such human-mediated disturbances disrupt the environmental heterogeneity and loss of biodiversity. All of these have constrained to develop condition for the decline of the productive ability of biological resources. In such context, it becomes imperative to lessen the human-mediated constrains, for inciting natural re-expression of productive potential of biotic community prior to undertaking any eco-restoration measures. Application of basic ecological principles in a natural-cultural context of rivers can imply restoration of ecological habitats and biodiversity in space and time for ensuring maximum bioproduction.

The concept of restoration has been emerged by reconstruction of the meaning of resources from the perspectives changing societal priorities. River restoration being a newly emerged scientific discipline has been maturing with rapid pace in view of the rising eco-degradation-based problems, contemplating on a long history of human intervention on rivers for a multifarious economic and social reasons., with an eye to understand wider relationship between nature and society .

However, continued ecological focus for achieving the stated goals for restoration, in bringing back the degraded ecosystems to its earlier normal state by not only applying the scientific principles but also adhering strictly on the legislative directives, for the successful eco-restoration., monitoring. The community-based restoration activity has also been assuming importance involving citizen science-monitoring frameworks, which put more emphasis on reanalyzing the existing data and information so that the existing knowledge base on river restoration can be integrated with the restoration motives in driving better project design and evaluation.

Blending of participatory approaches with the ecosystem goods and services approach have led to develop integration of different interests, approaches, world-views and objectives among the stakeholders which holds great promise to resolve the ongoing conflicts with. Keeping pace with the increasing ecological focus of stated goals for restoration, river restoration can, have wider objectives than simple ecological improvement, for example, community-building or re-engaging inhabitants of urban areas with their local environment. With proper demonstrating the overall benefit to river ecology and biodiversity. The history of river management highlights changes related to a highly dynamic relationship between nature and society.

Restoration can play an important role in the sustainable management of river systems, with the building of strong communities connected to their local environment and endowed with a strong sense of stewardship. Achieving both the ecological and social objectives for restoration, however, will require good planning, skilled facilitation, innovative research, and effective structures for learning. The objectives of river restoration especially in urban areas may be tied to larger goals of community building and regeneration.

New demands on river management require frameworks that are able to integrate social and scientific goals while still achieving core objectives, including legislative requirements. Large catchment basins being viewed as ecosystems are composed of interacting natural and cultural attributes. The river ecology of the present era puts more importance on the four-dimensional nature of the river continuum where the riverine biodiversity and bioproductivity are largely regulated by habitat manipulation and maintenance processes. Controlling of the flows within rivers and streams reduces annual flow amplitude and increases variation in base flow resulting in changes in the physicochemical variables and different ecological and biophysical patterns, processes, and attributes.

All of these ultimately lead to severe ecological connectivity between upstream and downstream reaches and between channels, groundwaters, and floodplains threating the indigenous biodiversity and bioproduction process and making avenues for the proliferation of non-native biota. Marked changes in the physical, chemical, and biological factors and processes are resulted from the alteration of flow variability which causes degradation of river ecosystem by developing an altered ecological conditions; the costs in terms of ecology are very high to both biodiversity and society (Postel and Carpenter 1997; IUCN 2000; WCD 2000).

Around the world, river scientists have been trying their best to have better options by which river flows can be altered to cater to meet the needs of human beings by maintaining ecological balances of the structure and function of natural ecological settings ecosystems (Poff et al. 1997; Richter et al. 1997b; Arthington and Zalucki 1998; King and Louw 1998). Integrity, health, and ecological sustainability water uses by human beings for myriad of purposes including municipal and industrial water supply, agricultural irrigation, hydroelectric power generation, waste assimilation, navigation, and recreation cause an alteration of the natural flow of rivers.

The main challenge before the human civilization is to ensure sustainable water management adhering strictly to the basic ecological principles as applicable to river ecosystem with development of suitable water management strategies by storing necessary amount of water for the optimum use for the human beings and also diverting the required amount of water to meet other human purposes in such a manner without causing eco-degradation. This is thought to be possible by maintaining a balance between the water demands and withdrawal keeping the river's natural flow patterns unaltered.

In addition, care should be made to preserve the ecological integrity of the suffered ecosystems, which experience the loss of indigenous species along with other ecologically important structural components in order to maintain the flow ecological services for the society.

10.14 Wild Life in India with Special Reference to Threatened Species

A total of **6495** mammal species are recorded from the world of which **96** species have already become extinct. Around **400** species of mammals that are believed to exist in India are extinct. A total of **8, 580** living species of birds belonging to **27** orders and **155** families are in existence across the world, of which a total of **1300** species of birds belonging to the class Aves so far recorded from the Indian subcontinent (Kazmierczak 2015) which is further divided into **2** subclasses and **20** orders. A total of **10, 000** reptile species are recorded from the world of which **518** species of reptiles in India of which **3** species of crocodiles, **34** species of turtles, and tortoises, **202** species of lizards, and **279** species of snakes belonging to **28** families. Approximate number of **8000** species of amphibian are found in the world of which about **410** species of amphibians are known from India and **50%** of the Indian amphibian species are endemic.

10.14.1 Threatened Mammalian Species

In India, out of four hundred (**400**) species of wild mammalian fauna, of which eighty one (**81**) species are endangered ones. Under the order primates of the class mammal, out of ninteen (**19**) different species, twelve (**12**) are endangerd, special mention to be made on Slender Loris (*Loris lydekkerianus*), Slow Loris (*Nycticebus coucang*), Lion-tailed Macaque (Macaca silenus); Pig-tailed Macaque(Macaca nemestrina leonina); Stumped tailed Macaque (Macaca arctoides); Crab-eating Macaque (*Macaca fascicularis*), Nilgiri Langur (*Trachypithecus johni*); Caped Langur (*Trachypithecus pileatus*) and Golden Langur (*Semnopithecus* geei), Phayre' s Leaf Monkey (*Trachypithecus phayrei*); Hoolock Gibon (*Hylobates hoolock*) etc. Hoolock gibbon is found in the forest tracts of the mountains of the north-eastern India. The order Pholidata includes two species – Chinese Pangolin (Manis pentadactyla aurita) and Indian Pangolin (*Manis crassicaudata*), both of which are under the threatened category. The number of wild faunal species under the order Carnivora is thirty six (**36**) which belong to twenty eight (**28**) genera and seven (**7**) families. The wild animals such as wolf (*Canis lupus*), jackal(*Canis aureus*), red fox (*Vulpes vulpes*), Indian fox (*Vulpes bengalensis*), and wild dogs (*Cuon alpinus*) belonging to only one family, Cannidae, have also become very much threatened although they were once very much abundant throughout the length and breadth of the country.

The family Ursidae under the order Carnivora have registered their steady decline in population which include Himalayan brown bear (*Ursus arctos*) which once enjoyed wide range of distribution from the mountain range of Kashmir in the western India to the east Himalayan forest tract at Sikkim, whereas the Malayan sun bear (*Helarctos malayanus*) restricts its distribution in the mountain ranges of north-east India, and the sloth bear (*Melursus ursinus*) prefers to abound in almost all the forests of India. The family Procyonidae under the order Carnivora includes only one species named as red panda (*Ailurus fulgens*), occasionally called as lesser panda or cat bear which is found only in the eastern Himalaya, and this animal is categorized as critically endangered wild fauna. Out of fourteen (**14**) different species under the family Mastolodae, only the species '**Ermine or Stoat**' (*Mustela erminea*) is only found in the forest tracts of western Himalaya. Similarly, out of fifteen (**15**) different species under the family "**Viverridae,**" only the species known as Malabar civet (*Viverra megaspila*) is thriving in the forest tracts of the extreme southern part of India near the sea coast. Other threatened species include tiger civet (*Viverricula indica*), spotted linsang (*Prionodon pardicolor*), or binturong (*Arctictis* binturong). The most notable wild fauna under the family Pholodae are Tiger (*Panthera tigris tigris*,**)**, Lion (*Panthera leo leo*) and different species of leopards such as Snow Leopard (*Panthera uncia*), The species Snow Leopard (*Panthera uncia*) usually inhabit in the forest tracts of Himalaya around five thousands meters above the sea level. So many lesser cats occur in different parts of Indian forests, especially in the eastern and north eastern regions, most threatened of which are Indian desert cat (*Felis silvestris*), lynx (*Felis lynx isabellina*), caracal (*Felis caracal*), jungle cat (*Felis chaus*), leopard cat (*Felis bengalensis*), Pallas cat (*Felis manul*), rusty-spotted cat (*Felis rubiginosa*), fishing cat (*Felis viverrina*), golden cat (*Felis temmincki*), marbled cat (*Felis marmorata*), and Clouded Leopard (*Neofelis nebulosa*). Another important charismatic species, Cheetah, has been disappeared from the forest of India and Indian subcontinents.

Besides, other important mammalian wild fauna are single-horned rhinoceros (Rhinoceros unicornis) which is now restricted its distribution only in the northern parts of West Bengal and in the state of West Bengal, India. Indian wild ass (*Asinus hemionus khur*) is only seen in the saline grass belt of **"Run of Kotch"** in the state of Gujarat, India. The mammalian order Artiodactyla includes thirty two **(32)** different species of which twenty species are endangered. The critically endangered species belonging to this family are Andaman Wild Pig (*Sus scrofa andamanensis*) and Pigmi Hog (*Sus salvanius*), the first two are only found in th Andaman and Nikobar Islands and the third one occurs in the foot hill of East Himalaya. Out of five (**5**) different endangered species belonging to the family **'Survidae'**, and the most threatened one is Hangul (*Cervus elephus hanglu*) which is only found to inhabit in the mountains of valleys of Kashmir. Others deers are Swamp Deer(*Cervus duvauceli*), Brownantlard, Dancing Deer, Manipur Thamin (*Cervus eldieldi*) which is only found to occur in the state of Manipur at the north-eastern froesr tracts of Himalaya,India and Musk Deer(*Moschus moschiferus*), that occurs in very small numbers in the Himalayan range from the Chamba valley to further east to Sikim. Out of twenty one (**21**) deer species belonging to the family **'Bovidae**', fourteen (14) species are very much threatened which are named Black buck or Krishnasar (*Antilope cervicapra*), Chinkara(*Gazella dorcas*), Chiru or Tibetan Antelope (*Pantholops hodgsoni*) Chousinga, Wild Buffalo (Bubalus arnee), Sapu, Markhar, Himalayan Iebekhs, Himalayan Tahr (*Hemitragus jemlahicus*),Great Tibetan Sheep (Ovis sp), Bharal/ Blue ship (*Pseudois nayaur*) Sero Takin/ Goat Antelop, Himalayan Tor etc. Only other rare logomorpha, named as Hispid Hare (*Caprolagus hispidus*) is observed in the grass belt of the state of Assam. Besides, the freshwater mammalian species, the Gangetic Dolphin (*Platanista gangetica*), is also under threats on their life.

10.14.2 Birds

These include geese, swans, pink-headed duck, white-winged wood duck, grey teal whooper swan, and mute swan. Eastern white stork, large whistling teal,Indian black-crested baza, blyth's baza, himalayan golden eagle, black eagle, many bawks, eagles and falcons, game birds, Bamboo partridge, Red spuriowl, painted spuri owl, forest spotted owl mountain quail, blood pheasant, satyr tragopan, Blyth's tragopan, several pheasants, koklas pheasant, chir pheasant, peacock pheasant, Pheasant -Grouse,Indian peafowl, several cranes like eastern common crane, blacknecked crane, Hooded crane, great white crane, masked finfoot, several bustards and floricans like little bustard, houbra bustard, the great Indian bustard, the Bengal florican, Indian skimmer, himalayan bearded vulture, the Nicobar pigeon, several frogmouths particularly Hodgson's frogmouth, the hornbills as white throated brown bornbill, the rufusnecked hornbill, the great pied hornbill, Indian pied hornbill and the Malabar pied hornbill.

10.14.3 Reptiles

Several turtle, tortoise and terrapin as leatherback or trunk turtle, the green sea turtle, the leather head and the hawksbill or tortoise shell turtle, the estuarine crocodile, mugger and the gharial; monitor lizards(Water monitor, Common Indian monitor); Indian python, Indian egg-eating snake.

10.14.4 Amphibian

The viviparous toad, Indian salamander,Malabar tree toad, Garo hills tree toad.

10.15 Sustainability: the Prime Objective of the Eco-Management of Riverine Ecosystem

Thus, concept ecologically sustainable water management are defined, refined, and modified putting more emphasis on human water demands of water for human beings and ecosystem requirements for achieving single, but one time solution.

The term "**sustainability**" appears to be the most comprehensive concept in the realm of environmental management and politics. In its broadest sense, sustainability assumes as an ethical precept, being more a concept of prediction instead of being definitional (Costanza and Patten 1995). In accordance with the Brundtland-commission report "**Our Common Future**" (World Commission on Environment and Development, 1987), three constituent fundamental components to sustainable development (environmental protection, economic growth, and social equity) should maintain a balance to "**sustain**" them for future generations. Applying the concept of sustainability to river systems implies that river management should set its aims to ecological as well as to economic and social functions (Leuven et al. 2000).

Human beings use water for a myriad of purposes including municipal and industrial water supply, agricultural irrigation, hydroelectric power generation, waste assimilation, navigation, and recreation cause an alteration of the natural flow of rivers. The main challenge before the human civilization is to ensure ecologically sustainable water management by designing and implementing a water management program that stores and diverts water for human purposes in such a manner without causing eco-degradation. This is thought to be possible by maintaining a balance between the limit of the withdrawal of total amount of water from a river and a limit in the degree to which the shape of a river's natural flow patterns can be altered. There should not be any compromise between the ecological integrity of the affected ecosystems and the result in the loss of native species and valuable ecosystem products and services for society. Thus, ecologically sustainable water management is an iterative process in which both human water demands and ecosystem requirements are defined, refined, and modified to meet human and ecosystem sustainability now and in the future, rather than a single, one time solution.

Human change the environment to suit themselves and rarely are such changes compatible with the needs of other species. Although, this fact is evident today, only a few generation ago it was not so obvious. The common belief until the middle of the twentieth century was that Earth's resources were unlimited. Human beings have used a seemingly endless variety of methods to harm the environment, until the severe alteration of species populations and habitats has reached alarming levels. Destroying habitat, however, is not only the problem.

Humanity has also been polluting what remains. However, humans have the ability to preserve those species living today numbering in the thousands that were once reduced to a tiny fraction of their original numbers. If humanity can be motivated to protect and nurture the world, old habits of exploitation and destruction can be minimized. The term endangered species has become a common phrase in the present world of vocabulary. Opinions of the subject are probably divergent, ranging from a desire by some peoples for unrestricted exploitation of the environment (with humans first, last, and always) to an inflexible policy for the protection for every species, regardless of the consequences. As with most things in life, enlightened compromise is usually the most sensible approach. To better understand the present situation of wildlife of this planet, one must put it in conservative perspective. The terms like ecological integrity or biological integrity are often used in the ecological subsystem as either concepts competing with ecosystem health or as synonyms for ecosystem health (Callicot et al. 1999). Both the concepts pertaining to integrity and health appear to be the observation that they all bear reference to qualities, i.e., characteristics of the system.

In everyday practice, the ecological or biological integrity concept also refers often to a pre-disturbance or pristine state (Karr 1999), experiencing and enjoying the ecosystem having species composition, diversity, and functional organization comparable to that of the natural habitat of the region' (Karr 1991). Furthermore, integrity appears to appeal above all things to the state of organization of a system, emphasizing structure and pattern as important features of the system, while processes are primarily necessary to attain and maintain these features (Callicot et al. 1999; Lenders 2003). The conceptual definitions illustrate that health primarily refers to functioning. Furthermore, health refers to a desired (flexible) condition as opposed to the absolute (rigid) condition that integrity refers to. When comparing **ecosystem health and ecological integrity** in relation to their purpose for river management, ecological integrity appears to be rather rigid as a guiding concept for management, referring to an absolute condition and offering few degrees of freedom for other functions (social and economic) within a broader coherent sustainability context.

1. Traditionally the assessment of river water quality has been based solely on the measurement of physical, chemical, and some biological characteristics.
2. Measurements of aquatic biota, to identify structural or functional integrity of ecosystems, as small group of biological ecosystem-level indicators which can assess river condition have recently gained acceptance for river assessment. However, physical and chemical features of the environment affect these indicators, the structure and function of which may be changed by human activities.
3. The term "**river health**" applied to the assessment of river condition and sets of ecosystem-level indicators which actually identify the physical, chemical, and biological characteristics to be integrated into measures rather than just observations of cause and effect.
4. Increased examination of relationships between environmental variables that affect aquatic biota, such as habitat structure, flow regime, energy sources,

water quality and biotic interactions, and biological condition, is required in the study of river health.

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All the prevailing ecological parameters are observed in an integrated manner not only for quantified recording but also to note the cause and effect. Besides recording of the relationships of aquatic biota with their surrounding ecological variables such as habitat structure, flow regime, energy sources, water quality and biotic interactions and biological condition that impse determing impacts on the aquatic biota,, are required in the study of river health.

10.16 Means to Manage Conflicts: Society, Economics, and Politics

Setting of management targets for river health should be based on the perception and intention of the society. Society may view a highly productive river as healthy and a stable river as important for control and dependability (Rapport 1989). Clearly, conflicts may arise if river ecosystems are found not to operate this way. Chapman (1992) makes the distinction between "hard science" (ecologists with dirty hands) and "soft science" (politicians determining scientific outcomes). Bringing together 'hard' and 'soft' science for protection of ecosystem health has been fraught with difficulties (Chapman 1992). Nevertheless, Karr (1991) points out that advances in river assessment came about because of recognition that water resource problems involve biological as well as physical/chemical, social, and economic issues.

Legal and administrative tools are generated in response to conflicts which are generally unavoidable and is in need of help in managing them. Such tools are frequently proposed in order to create rational systems of water management. The legal and administrative tools, acting as incentives or disincentives for water resources management, can assume different forms: rules on property and water uses, regulations with fines or other penalties in case of violation, water withdrawal charges, pollution charges, user fees, subsidies, etc. Land-related tools are land banking, consolidation of holdings, and nationalization of land. Economic sanctions and the price mechanism do play an important role both as regards the orientation as well as intensity of land and water use. Fees, subsidies, and market conditions in general may thus decrease or stimulate certain types of land use.

In Third World countries, popular participation is an often used term in the context of rural development. Generally speaking it is supposed to be democratic, or at least anti-bureaucratic, and even efficient. The perspective is certainly different in industrialized countries as compared to developing countries. In the former, it is not so much motivation that is needed for mobilizing the use of resources but rather a much more keen awareness and knowledge about impacts of current usage patterns.

Criteria for land–water integration in environmental management of water and land are closely interrelated parts of the natural environment. Most of the water in a river has earlier passed land. Most human land uses are water dependent, but influence at the same time water flow, seasonality and quality. This makes the water divide fundamental for the integration of land and water conservation, and the drainage basin is an appropriate unit for such integration.

Unavoidable environmental changes due to land and water development can in fact be seen as the price to be paid for improved quality of life. These changes can, however, be more or less harmful for a sustained productivity of the resources. A realistic goal is therefore environmentally sound management of land and water, implying the harmonization, in development, of environmental and socioeconomic interests in a basin. The role of environmental management should be to maintain both the productivity of the primary resources and their linkages. Coordination of land and water conservation and management should aim at an optimum of the net production on all the basin lands.

Land-use patterns must be based on actual levels of fertility as well as the possibilities for compensations of various losses incurred through an intensified land use. It is important to distinguish between development of a river basin to maximize the availability of water and the conservation and management of water for maximizing socioeconomic benefits in the river basin. Transbasin water transfers may reduce the importance of the drainage basin as a relevant terrestrial unit.

The water divide however remains as a natural membrane, in some respects separated from outer environments although passed by import/export flows of water and other goods. The drainage basin, for instance, retains its importance as a unit within which water and soils come into some sort of integration and, consequently, when determining the carrying capacity of the land and water bodies of the basin. When analyzing the problems due to urban growth, it may be particularly useful to divide the basin into interacting subregions with different characteristics in terms of background conditions, land use, and type of economy and to elaborate on their interconnections.

The general goal should be a balanced growth between rural and urban areas. Systems analysis may be useful as a decision aid tool for selection of appropriate strategies. The fact that the force behind the rural exodus into urban areas is the poor living conditions makes rural development crucial in trying to limit the massive urban growth in many developing countries. It is fundamental that legal and administrative tools are flexible enough for timely adaptation to changes in water uses and users, to consideration of water use priorities, and to special situations, such as those occurring during revere droughts and floods.

Since on the one hand legal/administrative mechanisms tend to be rigid and on the other economic mechanisms tend to be much more flexible in directing and motivating appropriate parties to respond to changing circumstances, one should not encourage rules that give precedence to certain uses and users or establish rigid criteria that must be obeyed under all circumstances. In many countries, particularly developing ones, there is a dual economic system – modern and traditional. It is important to take this fact into consideration when developing legal and administrative mechanisms in water management and word development.

10.17 Criteria for Land–Water Integration in Environmental Management

Water and land are closely interrelated parts of the natural environment. Most of the water in a river has earlier passed land. Most human land uses are water dependent but influence at the same time water flow, seasonality, and quality. This makes the water divides fundamental for the integration of land and water conservation and the drainage basin an appropriate unit for such integration. Unavoidable environmental changes due to land and water development can in fact be seen as the price to be paid for improved quality of life. These changes can, however, be more or less harmful for a sustained productivity of the resources. A realistic goal is therefore environmentally sound management of land and water, implying the harmonization, in development, of environmental and socioeconomic interests in a basin.

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References

Allan, J. 1987. Macro-invertebrate drift in a Rocky Mountain stream. *Hydrobiologia* 144: 261–268.

Allan, J.D., and A.S. Flecker. 1993. Biodiversity conservation in running waters. *Bioscience* 43: 32–43.

Arthington, A. Hand, and J.M. Zalucki. 1998. *Comparative evaluation of environmental flow assessment techniques: Review of methods*. Land and Water Resources Research and Development Corporation 27/98.

Basaguren, A., A. Elosegul, and J. Pozo. 1996. Changes in the trophic structure of benthic macroinvertebrate communities associated with food availability and stream flow variations. 81 (1): 79–91.

Bell, C.R., and L.J. Albright. 1981. Attached and free -floating bacteria in the Fraser River Estuary, British Columbia, Canada. *Marine Ecology Progress Series* 6 (3): 317–327.

Benke, A.C., R.L.I.I.I. Henry, D.M. Gillespie, and R.J. Hunter. 1985. Importance of snag habitat for animal production in southeasternstreams. *Fisheries* 10: 8–13.

Bethesda, M.D., B.L. Johnson, W.B. Richardson, and T.J. Naimo. 1995. Past, present, and future concepts in large river ecology. *Bioscience* 45: 134–141.

Blaike, P. 1985. *The political economy of soil erosion in developing countries*. New Rork: Wiley.

Blaike, P., and H. Brookfield. 1987. *Land degradation and society*. New york: Methuen.

Boon, P.L., and R.J. Shiel. 1990. Grazing on bacteria by zooplankton in Australian billabongs. *Australian Journal of Marine and Freshwater Research* 41: 247–257.

Boulton, A.J., and L.N. Lloyd. 1992. Flooding frequency and invertebrate emergence from dry floodplain sediments of the River Murray, Australia. *Regulated Rivers* 7: 137–151.

Bunn, S.E., and A.A. Arthington. 2002. Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. *Environmental Management* 30: 492–507.

Callicot, J.B. 2000. Harmoney between men and land -Aldo Leopold and the foundations ecosystem management. *Journal of Forestry* 38 (5): 4–13.

Chakraborty, S.K. 2017. Ecological services on intertidal benthic fauna and the sustenance of coastal wetlands along the Midnapore(East) coast, West Bengal,India. In *Coastal wetlands: Alteration and remediation*, 777–886. Springer International Publishing AG part of Springer Nature.

———. 2018. Bioinvasion and environmental perturbation: Synergistic impact on coastal – mangrove ecosystems of West Bengal, India. In *Impacts of invasive species on coastal* *environments: Coast in crisis*, ed. C. Makowski and C. Finkl, 171–245. Springer International Publishing AG part of Springer, Nature.

Chapman, D. 1992. Chapter 1: An introduction to water quality. In *Water quality assessments -A guide to use biota, sediments and water in Environmental Monitoring*, 1–21. UNESCO/UNDP.

Chessman, B., S. Williams, and C.H. Besley. 2007. Bioassessment of streams with macroinvertebrates: Effect of sampled habitat and taxonomic resolution. *Journal of the North American Benthological Society* 26 (3): 546–565.

Cole, D.N., and J.L. Marion. 1988. Recreation impacts in some riparian forests of the eastern United States. *Environment Management* 12 (1): 99–107.

Costanza, R., and B.C. Patten. 1995. Defining and predicting sustainability. *Ecological Economics* 15: 193–196.

Cotner, J.B., J.V. Montoya, D.L. Roelke, and K.O. Winemiller. 2006. Seasonally variable riverine production in the Venezuelan llanos. *Journal of the the North American Benthological Society* 25: 171–184.

Crome, F.H.J. 1986. Australian waterfowl do not necessarily breed on a rising water level. *Aust. Wildl. Research* 13: 461–480.

Crome, F.H.J., and S.M. Carpenter. 1988. Plankton community cycling and recovery after drought -dynamics in a basin on a flood plain. *Hydrobiologia* 164: 193–211.

Darrigran, G. 1997. Invading bivalves in South America. *Alliens (Invasive Species Specialist Group Newsletter)* 5: 3.

Day, F.P. 1875–78. *The fishes of India: Being a natural history of the fishes known to inhabit the seas and fresh waters of India, Burma and Ceylon*. London: B. Quaritch.

Dudgeon, D. 2000a. Large-scale hydrological changes in tropical Asia: Prospects for riverine biodiversity. *Bioscience* 50: 793–806.

Dudgeon, D. 2000b. Riverine wetlands and biodiversity conservation in tropical Asia. In *Biodiversity in wetlands: Assessment, function and conservation*, ed. B. Gopal, W.J. Junk, and J.A. Davis, 1–26. The Hague: Backhuys.

———. 2000c. The ecology of tropical Asian rivers and streams in relation to biodiversity conservation. *Annual Review of Ecology and Systematics* 31: 239–263.

Dudgeon, D., A.H. Arthington, M.O. Gessner, et al. 2006. Freshwater biodiversity: Importance, threats, status and conservation challenges. *Biological Reviews* 81: 163–182.

Frissell, C.A., W.J. Liss, C.E. Warren, and M.D. Hurley. 1986. A hierarchical framework for stream habitat classification: Viewing streams in a watershed context. *Environmental Management* 10: 199–214.

Frisell, C.A., W.J. Liss, C.E. Warren, and M.D. Hurley. 1996. A hierarchical framework for stream habitat classification: Viewing streams in a watershed context. *Environmental Management* 10: 199–214.

Fry, B., and E.B. Sherr. 1984. 613c measure- ments as indicators of carbon flow in marine and freshwater ecosystems. *Contributions in Marine Science* 27: 13–47.

Gehrke, P.C., and J.H. Harris. 2001. Regional- scale effects of flow regulation on lowland riverine fish communities in New South Wales, Australia. *Regulated Rivers: Research and Management* 17: 369–391.

Gehrke, P.C., K.L. Astles, and J.H. Harris. 1999. Within -catchment effects of flow alteration on fish assemblages in the Hawkesbury-Nepean River system, Australia. 15 (1–3).

Gehrke, P.C., D.M. Gilligan, and M. Barwick. 2002. Changes in fish communities of the Shoalhaven River 20 years after construction of Tallowa Dam, Australia. *River Research and Applications.* 18 (3): 265–286.

Gibert, J., M.J. Dole-Olivier, P. Marmonier, and P. Vervier. 1990. *Surface water -ground water ecotones. The ecology and Management of Aquatic-Terrestrial Ecotones*, ed. R.J. Naiman and H. Decamps, 199–216. Paris/Carnforth: UNESCO MAB and the Parthenon Publishing Group.

Graca. 2001a. Litter processing along a stream gradient: The role of invertebrates and decomposers. *Journal of North American Benthological Society* 20 (3): 408–420.

Graca, Manuel A.S. 2001b. The role of invertebrates on leaf litter decomposition in streams – A review. *International Review of Hydrobiology* 86 (4–5).

Graca, M.A.S., R.C.F. Ferreira, and C.N. Coimbra. 2001. Litter processing along a stream gradient: The role of invertebrates and decomposers. *Journal of North American Benthological Society* 20 (3): 408–420.

Harding, J.S., E.F. Benfield, P.V. Bolstad, G.S. Helfman, and E.B.D. Jones. 1998. Stream biodiversity: The ghost of land use past. *Proceedings of the National Academy of Sciences of the United States of America* 95: 14843–14847.

Harris, J., and P.C. Gehrke. 1997. *Fish and Rivers in stress: The NSW Rivers survey*. Sydney: NSW Fisheries Office of Conservation and the CRC for Freshwater Ecology.

Hocutt, C.H., and E.O. Wiley. 1986. *The zoogeography of North American freshwater fishes*. Toronto: Wiley.

IUCN (International Union for the Conservation of Nature). 2000. *Vision for water and nature: A world strategy for conservation and sustainable management of water resources in the 21st century*. Gland/Cambridge: International Union for the Conservation of Nature.

Jenkins, R.E., and N.M. Burkhead. 1994. *Freshwater fishes of Virginia*. American Fisheries Society.

Johnson, B.L., W.R. Richardson, and T.J. Naimo. 1995. Past, present, and future concepts in large river ecology. *Bioscience* 45: 134–141.

Junk, W.J., and K.M. Wantzen. 2004. The flood pulse concept: New aspects, approaches, and applications—An update. In *Proceedings of the SecondInternational symposium on the Management of Large Rivers for fisheries*, ed. R.L. Welcomme and T. Petr, vol. 2, 117–149. Food and Agriculture Organization & Mekong River Commission. FAO Regional Office for Asia and the Pacific, Bangkok. RAP Publication.

Junk, W.J., P.B. Bayley, and R.E. Sparks. 1989. The flood pulse concept in river-floodplain systems. In *Proceedings of the international large river symposium*, ed. D.P. Dodge, Canadian Special Publication of Fisheries and Aquatic Sciences 106:110–27.

Karr, J.R. 1991. Biological integrity: A long-neglected aspect of water resource management. *Ecological Applications* 1: 66–84.

———. 1999. Defining and measuring river health. *Freshwater Biology* 41: 221–234.

Karr, J.R., and E.W. Chu. 1998. Sustaining living rivers. *Hydrobiologia* 422-423: 1–14.

Kazmierczak, K. 2000. *A field guide to the birds of India, Sri Lanka, Pakistan, Nepal, Bhutan, Bangladesh and Maldives*, 352. New Delhi: OmBook Service.

King, J., and D. Louw. 1998. Instream flow assessments for regulated rivers in South Africa using the building block methodology. *Aquatic Ecosystem Health and Management* 1: 109–124.

Kingsford, R.T. 1996. Wildfowl (Anatidae) movements in arid Australia. *Gibier Faune Sauvage, Game Wildlife* 13: 141–155.

Kingsford, R.T., and W. Johnson. 1999. The impact of water diversions on colonially nesting waterbirds in the Macquarie marshes in arid Australia. *Colonial Waterbirds* 21: 159–170.

Kingsford, R.T., and J.L. Porter. 1994. Waterbirds on an adjacent freshwater lake and salt lake in arid Australia. *Biological Conservation* 69: 219–228.

Lake, P.S. 1995. Of droughts and floods: River and stream ecosystems of Australia. In *River and stream ecosystems*, ed. C.E. Cushing, K.W. Cummins, and G.W. Minshall, 659–694. Amsterdam: Elsevier.

Lenders, H.J.R., B.G.W. Aarts, H. Strijbosch, and G. Van der Velde. 1998. The role of reference and target images in ecological recovery of river systems: Lines of thought in the Netherlands. In *New concepts for sustainable management of river systems*, ed. P.H. Neinhuis, R.S.E.W. Leuven, and A.M.J. Ragas, 35–52. Leiden: Backhuis.

Leopold, L.B., M.G. Wolman, and J.P. Miller. 1964. *Fluvial processes in geomorphology*, 552. San Francisco: Freeman.

Leuven, R.S.E.W., and I. Poudevigne. 2002. Riverine landscape dynamics and ecological risk assessment. *Freshwater Biology* 47: 845–865.

Leuven, R.S.E.W., A.M.J. Ragas, A.J.M. Smits, et al., eds. 2006. Living rivers: Trends and challenges in science and management. *Hydrobiologia* 565: 1–371.

Maher, M. 1984. Benthic studies of waterfowl breeding habitat in South-Western New South Wales. I. The fauna. *Australian Journal of Marine and Freshwater Research* 35: 85–96.

Maher, M., and S.M. Carpenter. 1984. Benthic studies of waterfowl breeding habitat in South-Western New South Wales. II. Chironomid populations. *Australian Journal of Marine and Freshwater Research* 35: 97–110.

Maheshwari, B.L., K.F. Walker, and T.A. McMahon. 1995. Effects of regulation on the flow regime of the river Murray, Australia. *Regul. Riv.* 10: 15–38.

Maltby, L. 1992. Detritus processing. In *The rivers handbook*, ed. P. Calow and G.E. Petts, vol. 1, 331–353. Oxford: Blackwell Scientific Publications.

Marchant, R. 1989. Changes in the benthic invertebrate communities of the Thomson river, southeastern Australia, after dam construction. *Regulated Rivers: Research and Management* 4 (1): 71–89.

McClain, M.E., ed. 2002. *The ecohydrology of South American rivers and wetlands*. International Association of Hydrlogical Sciences, UK as IAHS special publication No.6.

Merritt, R.W., and K.W. Cummings. 1996. *An introduction to the aquatic insects of North America*. Dubuque: Kendall/Hunt Publishing Company.

Minshall, G.W. 1984. Aquatic insect-substratum relationships. In *The ecology of aquatic insects*, ed. V.H. Resh and D.M. Rosenberg, 358–400. New York: Praeger Publishers.

Minshall, G.W., R.C. Peterson, K.W. Cummins, T.L. Bott, J.R. Sedell, C.E. Cushing, and R.L. Vannote. 1983. Interbiome comparison of stream ecosystem dynamics. *Ecological Monographs* 53: 1–25.

Montoya, J.M., S.L. Pimm, and R. Sole. 2006. Ecological networks and their fragility. *Nature* 442 (7100): 259–264.

Naiman, R.J. 1983. The influence of stream size on the food quality of seston. *Canadian Journal of Zoology* 61: 1995–2010.

Nelson, L.L., and E.B. Allen. 1993. Restoration of Stipa pulchra grass- lands: Effects of mycorrhizae and competition from Avena barbata. *Restoration Ecology* 1: 40–50.

Newbold, J.D., J.W. Elwood, R.V. O'Neill, and W. Van Winkle. 1981. Measuring nutrient spiralling in streams. *Canadian Journal of Fisheries and Aquatic Sciences* 38: 860–863.

Outridge, P.M. 1988. Seasonal and spatial variations in benthic macroinvertebrate communities. *Hydrobiologia* 150: 95–107.

Poff, N.L., and J.V. Ward. 1989. Implications of streamflow variability and predictability for lotic community structure: A regional analysis of streamflow patterns. *Canadian Journal of Fisheries and Aquatic Sciences* 46: 1805–1818.

Poff, N.L., J.D. Allan, M.B. Bain, J.R. Karr, K.L. Prestegaard, B.D. Richter, R.E. Sparks, and J.C. Stromberg. 1997. The natural flow regime: A paradigm for river conservation and restoration. *Bioscience* 47: 769–784.

Postel, Sandra, and Stephen Carpenter. 1997. *Freshwater ecosystem services, Nature's services: Societal dependence on natural ecosystems*, ed. Gretchen C. Daily, 195–214. Washington, DC: Island Press.

Power, M.E. 1990. Effects of fish in river food webs. *Science* 250: 811–814.

———. 1992. Habitat heterogeneity and the functional significance of fish in river food webs. *Ecology* 73: 1675–1688.

Power, M.E., D. Tilman, et al. 1996. Challenges in the quest for keystones. *Bioscience* 46 (8): 609–620.

Power, M.E., M.S. Parker, and W.E. Dietrich. 2008. Seasonal reassembly of a river food web: Floods, droughts, and impacts of fish. *Ecological Monographs* 78: 263–282.

Pringle, C.M., and T. Hamazaki. 1997. Effects of fishes on algal response to storms in a tropical stream. *Ecology* 78: 2432–2442.

Puckridge, J.T., F. Sheldon, K.F. Walker, and A.J. Boulton. 1998. Flow variability and the ecology of large rivers. *Marine and Freshwater Research* 49 (1): 55–72.

Rapport, D.J. 1989. What constitutes ecosystem health ? *Perspectives in Biology and Medicine* 33: 120–132.

Resh, V.H., A.V. Brown, A.P. Covich, M.E. Gurtz, H.W. Li, G.W. Minshall, S.R. Reice, A.L. Sheldon, J.B. Wallace, and R. Wissmar. 1988. The role of disturbance in stream ecology. *Journal of the North American Benthological Society* 7: 433–455.

Richards, C., L.B. Johnson, and G.E. Host. 1996. Landscape scale influences on stream habitats and biota. *Canadian Journal of Fisheries and Aquatic Sciences* 53: 295–311.

Richey, J.E., and others. 1986. Water discharge and suspended sediment connections in the Amazon River: 1982–1984. *Water Resources Research,* 22: 756–764.

Richey, J.E., J.I. Hedges, A.H. Devol, P.D. Quay, R. Victoria, L. Martinelli, and B.R. Forsberg. 1990. Biogeochemistry of carbon in the Amazon River. *Limnology and Oceanography* 35: 352–371.

Ritcher, B.D., J.V. Baumgartner, R. Wigington, and D.P. Braun. 1997. How much water does a river need ? *Freshwater Biology* 37: 231–249.

Rosi-Marshall, E.J., and J.B. Wallace. 2002. Invertebrate food webs along a stream resource gradient. 47: 129–141.

Schinberg, A., and K.A. Gould. 1994. *Environment and society: The enduring conflict*, 1–324. New York: St. Martins Press.

Schumm, S.A., and R.W. Lichty. 1963. Channel widening and flood-plain construction along Cimarron River, southwestern Kansas: U.S. Geol. Survey Prof 352-E.

Southwood, T.R.E. 1977. Habitat, the templet for ecological strategies. *Journal of Animal Ecology* 46: 337–365.

Sparks, R.E., P.B. Bayley, S.L. Kohler, and L.L. Osborne. 1990. Disturbance and recovery of large floodplain rivers. *Environmental Management* 14: 699–709.

Swanson, F.J., T.K. Kratz, N. Caine, and R.G. Woodmanse. 1988. Landform effects on ecosystem patterns and processes. *BioScience* 38 (2): 98.

Swanston, D.N. 1991. Natural processes. *American Fisheries Society Special Publication* 19: 139–179.

Thoms, M.C., and M. Parsons. 2002. Eco-geomorphology: An interdisciplinary approach to river science. *International Association of Hydrological Sciences* 276: 113–120.

———. 2003. Identifying spatial and temporal patterns in the hydrological character of the Condamine-Balonne River, Australia, using multivariate statistics. *River Research and Applications* 19: 443–457.

Thoms, M.C., and F. Sheldon. 1997. River channel complexity and ecosystem processes: The Barwon-Darling River (Australia). In *Frontiers in ecology: Building the links*, ed. N. Klomp and I. Lunt, 193–205. London: Elsevier.

———. 2000. Australian lowland rivers: an introduction. *Regulated Rivers: Research and Management* 16: 375–384.

Thoms, M.C., and K.F. Walker. 1989. Preliminary observations of the environmental effects of flow regulation on the river Murray, South Australia. *South Australian Geographical Journal* 89: 1–14.

Thoms, M.C., M. Southwell, and H.M. McGinness. 2005. Water resource development and the fragmentation of floodplain river ecosystems. *Geomorphology* 71: 126–138.

Thorp, J.H., and M.D. Delong. 1994. The riverine productivity model: An heuristic view of carbon sources and organic processing in large river ecosystems. *Oikos* 70: 305–308.

Townsend, C.R., and A.G. Hildrew. 1994. Species traits in relation to a habitat templet for river systems. *Freshwater Biology* 31: 265–275.

Townsend, C.R., S. Dolédec, and M.R. Scarsbrook. 1997. Species traits in relation to temporal and spatial heterogeneity in streams: A test of habitat templet theory. *Freshwater Biology* 37: 367–387.

Vannote, R.L., G.W. Minshall, K.W. Cummins, J.R. Sedell, and C.E. Cushing. 1980. The river continuum concept. *Canadian Journal of Fisheries and Aquatic Sciences* 37: 130–137.

Walker, K.F. 1985. A review of the ecological effects of river regulation in Australia. *Hydrobiologia* 125: 111–129. Dr W. Junk Publishers, Dordrecht. Printed in the Netherlands.
Walker, K.F., and M.C. Thoms. 1993. Environmental effects of flow regulation on the lower river Murray, Australia. *Regulated Rivers, Research and Management* 8: 103–119.
Walker, K.F., and M.C. Thoms. 1993. A case history of the environmental effects of flow regulation on a semi-arid lowland river: The river Murray, South Australia. *Regulated Rivers: Research and Management* 8: 103–119.
Walker, K.F., F. Sheldon, and J.T. Puckridge. 1995. A perspective on dryland river ecosystems. *Regulated Rivers: Research and Management* 11: 85–104.
Ward, J.V. 1998. Riverine landscapes: Biodiversity patterns, disturbance regimes and aquatic conservation. *Biological Conservation* 83: 267–278.
Ward, J.V., and J.A. Stanford. 1983a. The serial discontinuity concept of lotic ecosystems. In *Dynamics of lotic ecosystems*, ed. T.D. Fontaine and S.M. Bartell, 29–42. Ann Arbor: Ann Arbor Science.
———. 1983b. The intermediate disturbance hypothesis: An explanation for biotic diversity patterns in lotic ecosystems. In *Dynamics of lotic ecosystems*, ed. T.D. Fontaine and S.M. Bartell, 347–356. Ann Arbor: Ann Arbor Science Publishers.
———. 1983c. The serial discontinuity concept of lotic ecosystems. In *Dynamics of lotic ecosystems*, ed. T.D. Fontaine III and S.M. Bartell, 43–68. Ann Arbor: Ann Arbor Science.
Warren, C.E., and W.J. Liss. 1983. *System classification and modelling of watersheds and streams*, Unpublished report, 1–193. Corvallis: Department of Fisheries and Wildlife, Oregon State University.
Warren, C.E., J. Alllen, and J.W. Haefner. 1979. Conceptual frameworks and the philosophical foundations of general living systems theory. *Behavioral Science* 24: 296–310.
WCD (World Commission on Dams). 2000. *Dams and development: A new framework for decision -making*, Report of the World Commission on Dams. London: Earthscan.
Welcomme, R.L., and S.A. Hall. 2001. Some considerations of the effects of differences in flood patterns on fish populations. *Eco hydrology and Hydrobiology* 1: 313–321.
Winemiller, K.O., J.V. Montoya, D.L. Roelcke, C.A. Layman, and J.B. Cotner. 2006. Seasonally varying impact of detritivorous fishes on the benthic ecology of a tropical floodplain river. *Journal of North American Benthological Society* 25: 250–262.
Woodward, G., and A.G. Hildrew. 2002. Food web structure in riverine landscapes. *Freshwater Biology* 47: 777–798.
Yang, T., Q. Zhang, Y.D. Chen, X. Tao, Chong-yu, Xu, and Xi Chen. 2008, 2010. A spatial assessment of hydrologic alteration caused by dam construction in the middle and lower Yellow River, China. *Hydrological Processes,* 22: 3829–3843.
Yang, H., P. Xie, L.Y. Ni, and R.J. anfd Flower. 2012. Pollution in the Yangtze. *Science* 337: 410–410.

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