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Biodiversity in India: Status, Issues and Challenges

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Part I
Introduction

Chapter 1
Introduction

Ravinder Kumar Kohli, H. P. Singh, Amarpreet Kaur, D. R. Batish, and Shalinder Kaur

1.1 Introduction

"Biological diversity" means 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: this includes diversity within species, between species and of ecosystems (CBD 1992). The term *biodiversity* is a contraction of *biological diversity* and is credited to Edward O. Wilson who first used the term in 1986 during a conference (Wilson 1988). Human beings are substantially benefitted from these biodiverse ecosystems. Apart from provisional (food, fodder, fiber, timber, and medicines) and regulating (pollination, climate regulation, carbon sequestration and nutrient cycling) services, biodiversity also ensures non-material benefits and long-term flow of these ecosystem services by offering resistance and resilience against natural disturbances (Díaz et al. 2018). In fact, 13 of the 17 Sustainable Development Goals (SDGs) of United Nations are dependent on biodiversity. However, exploitation of these natural reserves in an unsustainable manner by the ever-growing human population has resulted in their loss at an unprecedented rate (Cardinale et al. 2012, IPBES 2019). As per the Global Assessment on Biodiversity and Ecosystem Services, about 75% of land environment and ¬ 66% of the marine environment have been altered by humans (IPBES 2019). Besides, other human-induced environmental and land-use changes have further exacerbated these losses, leading to the extinction of certain species (or their distinct subpopulations) and disruption of ecological processes (WWF 2020). Such irreversible changes even

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in the smallest of ecosystems can break down the entire functioning of a global biosphere, and therefore, biodiversity loss is a primary concern for ecologists and environmentalists.

1.2 Biodiversity in India

India, because of its location and diversity in climatic regions ranging from very cold to extremely hot, is one of the 17 mega-diverse countries in the world. It houses about 8% of the recorded species of the world with high endemism. India has a rich cultural diversity studded with a vast repository of traditional knowledge associated with biological resources. Over 97,642 species of animals (6.38% of the world; Venkataraman et al. 2020) in 10 biogeographic regions and 49,441 of plants (algae, fungi, bacteria, lichens, bryophytes, pteridophytes, gymnosperms, angiosperms; BSI 2019) accounting for 10.61% of global plant species recognized in 11 phytogeographic zones have been reported in India.

The fauna found in India includes 427 species of mammals, 1340 species of birds, 584 species of reptiles, and 407 species of amphibians (Table 1.2). On the other hand, among plant species, there are 18,666 flowering plants, over 1300 pteridophytes, more than 80 gymnosperms, and 17% of the world's bryophytes (Table 1.1).

There is a high level of endemism (~23%) in plant species found in India. A total of 11,554 plant species are endemic in India including 12 gymnosperms, 4303 angiosperms, 629 bryophytes, 66 pteridophytes, 1924 algae, 4100 fungi, and 520 lichens. All the endemic gymnosperms in India are threatened with one being critically endangered. Six angiosperms have been reported to be extinct, whereas two are extinct in wild (BSI 2019). India is one of the world's eight Vavilov's centers of origin of cultivated crop plants, with rice, red gram, chickpea, owpea, mung bean, eggplant, cucumber, sugarcane, black pepper, moth bean, rice bean, cotton, turmeric, indigo, millets, bread wheat, club wheat, sesame, linseed, muskmelon, carrot, onion, garlic, apricot, grape, hemp, cotton, etc. being originated in the country. Similarly, high endemism has been reported for various species of amphibians, lizards, insects, marine fauna, centipedes, mayflies, and freshwater sponges. About 12.6% of mammals, 46% of reptiles, and 56% of amphibians found in India are endemic. India hosts about 170 critically endangered animals. The level of diversity of biota in India

Table 1.2 A comparative position of species biodiversity in India among other mega-diverse countries of the world

Group	Rank among mega-diverse countries
Higher plants	IX
Mammals	VII
Birds	X
Reptiles	V
Amphibian	VII
Fishes	I

Source: https://www.cbd.int/countries/profile/?country=in

Table 1.1 An outline of the number of species in major groups of plants, microorganisms, and animals in India in comparison to the world

Taxonomic groups	Types in India	Types in world	% of world
Virus/bacteria	1223	11,813	10.35
Algae	7411	40,000	18.53
Fungi	15,396	98,998	15.55
Lichens	2581	17,000	15.18
Bryophytes	2780	16,236	17.12
Pteridophytes	1302	12,000	10.85
Gymnosperms	82	1021	8.03
Angiosperms	18,666	2,68,600	6.95
Mammals	427	5853	7.29
Bird	1340	10,357	12.9
Reptiles	584	10,450	5.58
Amphibians	407	7667	5.30
Fishes	3364	34,362	9.78

Source: BSI (2019), Venkataraman et al. (2020)

Table 1.3 An overview of biodiversity hotspots in India

Vital status	Western Ghats (and Sri Lanka)	Indo-Burma	Himalayas	Sundaland
Hotspot original extent (km^2)	189,611	2,373,057	741,706	1,501,063
Hotspot vegetation remaining (km^2)	43,611	118,653	185,427	100,571
Loss in vegetation (%)	77%	95%	75%	93.3%
Endemic plant species	3049	7000	3160	15,000
Endemic threatened birds	10	18	8	43
Endemic threatened mammals	14	25	4	60
Endemic threatened amphibians	87	35	4	59
Extinct species	20	1	0	4
Human population (people/km^2)	261	134	123	153
Protected area (km^2)	26,130	235,758	112,578	179,723

Source: https://www.bsienvis.nic.in/files/biodiversity%20Hotspots%20in%20India.pdf

and ranking among the mega-diverse countries are very encouraging (Table 1.2). According to Conservation International, India is ranked as the most mega-diverse country in terms of different species of fishes recorded from its marine and fresh-water habitats (Table 1.2).

Of the 36 biodiversity hotspots recognized world over, four (Himalayas, Indo-Burma, Western Ghats and Sri Lanka, and Nicobar Islands in Sundaland hotspot) are present in India (Table 1.3).

1.3 Cultural Linkage to Biodiversity

Indian culture and literature teach respect for biotic and abiotic components of biodiversity. It has been suggested that for the first time in the world, laws for the protection of wildlife were enacted in the third century in India by Emperor Ashoka. Protection of plants and animals has always been a part and parcel of the rich culture of India. India is perhaps the only country where the protection of living beings is associated with religion and the plants and animals are worshiped in relation to different gods and goddesses.

Several deities have been associated with different wild and domestic animals. Animals such as deer have consistently been associated with *Lord Brahma* (Hindu deity), whereas *garud* (a mythological creature mix of eagle and human), lion, and sheshnag (mystical five-headed snake) are often seen with *Lord Vishnu* (Hindu deity) (Table 1.4). *Nandi* (the bull) is the vehicle of Lord *Shiva* (Hindu deity) and reflects his legendary virility. Shiva is also described holding snake as a garland around his neck, signifying his status as *nageshwar*, Lord of the Snakes (Table 1.4). *Ganesha* is another Hindu deity, represented as a human with an elephant head, and travels using *mushak* (mouse). Similarly, deities like Lord Hanuman and Lord Krishna are associated with monkey and cow, respectively.

Medicinal plant species such as neem (*Azadirachta indica*), Bel (*Aegle marmelos*), and Tulsi (*Ocimum sanctum*) are associated with Hindu gods and goddesses and often planted and worshipped in households. It is believed that these plants not only cure common diseases but wipe away the negative energy and fill the surroundings with positivity, good health, and prosperity. Gautam Buddha, the spiritual teacher associated with Buddhism, is said to have attained enlightenment under *Ficus religiosa*, and hence, the tree is considered sacred and worshipped by the people. Kadamb (*Neolamarckia cadamba)* is considered favorite tree of Lord Krishna (Hindu deity), and mango (*Mangifera indica*). Tulsi is considered incarnation of Goddess Laxmi and revered and used for worship of Lord Vishnu and Krishna. *Saraca asoca* (Ashoka tree) is considered sacred and worshipped in

Table 1.4 Cultural linkage to wildlife: Indian culture and literature teach non-violence and respect for biota wildlife which has enjoyed linkage with religious ideals and sentiments

Gods associated with animals		Gods associated with trees	
Brahma	Deer	Neem	Sitla
Vishnu	Garud, lion, cobra	Banyan	Sheshnag
Shiva	Bull Nandi, snake	Tulsi	Lakshmi, Vishnu
Ganesha	Elephant, Mushak	Bel	Shiva
Durga	Lion	Ficus	Buddha
Krishna	Cow	Ashoka	Indra
Saraswati	Swan	Kadamb	Krishna
Hanuman	Monkey	Mango	Lakshmi
Guru Gobind Singh	Bagh	Pipal	Vishnu and Krishna
		Lotus	Saraswati

Hinduism and Buddhism. The tree has been mentioned widely in Indian ancient books and in Ramayana, and Goddess Sita was kept in *vatika* (garden*)* having this tree in Sri Lanka. Lord Buddha is believed to be born under Ashoka tree in Lumbini Garden.

Kusha or Darbha or Doorbha grass (*Desmostachya bipinnata*) is widely used in Hindu, Jain, and Buddhist religions for sacred ceremonies including Puja, etc. Its use has been mentioned in Rigveda, Vishnupuram, and Bhagavad Gita. The flower of lotus (*Nelumbo nucifera*) is used during worshipping of Goddess Lakshmi and considered a symbol of purity in Buddhism. In fact, it is the most important flower and strongly associated with religious ceremonies and is the national flower of India. Several flowers have been used for offerings and worshipping (puja) deities. For example, lotus is used as offering to Goddess Lakshmi, Palash or parrot tree (*Butea monosperma*) to Goddess Saraswati, Jamine (Chameli) to Lord Hanuman, Prajita or Indian Magnolia to Lord Vishnu, Red Hibiscus to Goddess Kali, *Calotropis* and Datura flower to Lord Shiva, and *Nerium oleander* to Maa Durga. The sacredness and religious importance of many flowers have been manifested in their adoption as state flower, for example, Brahma Kamal in Uttarakhand and Palash in Bihar and Madhya Pradesh.

Several plants found in remote and pristine areas in high mountains have been mentioned in ancient Hindu texts and mythology for their offerings to deities and Gods. For example, flowers of Brahma Kamal (*Saussurea obvallata*; Lotus of Brahma), found at high altitude (3000–4800 m) in Himalayas, has been linked to Brahma (The Creator God), is linked to Lord Shiva and Lord Brahma, and even finds reference in epics like Ramayana and Mahabharata. Moreover, several wildflowers and fruits are used by local communities and tribes in remote areas during local festivals and worship of deities as a part of their culture and tradition. The use of traditions, rules, and religious beliefs is strongly linked to the cultural identity of tribal communities and the use of native plants for various ceremonies. These cultural and religious beliefs teach the importance of biodiversity and encourage conservation of the plants and wildlife. However, good traditions and reverence for biodiversity are declining at a fast pace.

1.4 Protected Area Networks in India

Due to anthropogenic reasons, many epiphytic and herbaceous plants have disappeared from their endemic regions in India, and several orchids, ferns, cycads, and medicinal herbs are categorized as endangered. Among the faunal diversity, many mammals, birds, reptiles, corals, and fishes have been assigned a threatened status in the country. As per the Living Planet Report of 2020, in India around *3%* of bird species face extinction; *19%* of amphibians are threatened or critically endangered, and over *12%* of wild mammals are threatened with extinction (WWF 2020). To protect its biodiversity, several protected areas and conservation sites have been declared in India, and nearly 5% of its total area is formally classified as protected

Table 1.5 An overview of protected area networks in India (as of December 28, 2020)

Protected areas	Number
National parks	106
Wildlife sanctuaries	564
Conservation reserves	99
Community reserves	218
Tiger reserves	52
Elephant reserves	30
Biodiversity heritage sites	18
Key biodiversity areas	531

Adapted from WIIENVIS, https://wiienvis.nic.in

(WIIENVIS 2020). As of 8 February 2022, India has a network of 987 protected areas including 106 national parks, 564 wildlife sanctuaries, 99 conservation reserves, and 218 community reserves covering a total of 173,053.69 km^2 of the geographical area of the country which is approximately 5.26% (Table 1.5). In addition, 131 marine protected areas have been recognized in peninsular areas and islands of India to protect and conserve marine species. The International Union for Conservation of Nature (IUCN) has recognized 531 sites in Key Biodiversity Areas in India. Likewise, 18 sites have been identified as Biodiversity Heritage Sites by National Biodiversity Authority, India, to protect and conserve the unique biodiversity and fragile ecosystem of these areas (NBA India, http://nbaindia.org/content/106/29/1/bhs.html). The Government of India under the aegis of the Ministry of Environment, Forests and Climate Change has instituted sites of conservation importance to protect species such as tiger, elephants, crocodile, bird, etc. Project Tiger, which was started in the year 1972, now comprising 52 Tiger reserves, is a major effort to conserve tiger and their habitats in the country. Similarly, Project Elephant was started in 1992, and at present 30 such reserves have been established for the protection of elephants. Many such programs have been undertaken for the conservation of crocodiles, rhinos, and birds. To protect and conserve the rich biodiversity of wetlands, 41 sites have been included under Ramsar Convention as Ramsar Wetlands of International Importance. These conservation practices have yielded variable success rate, but many more efforts are required to conserve the mega-diversity of the country.

1.5 Way Forward

According to the World Bank, India is categorized under lower middle economies, and in developing countries like India, there are additional hindrances in the application of conservation approaches such as lack of adequate finances, insufficient scientific capacities, and minimal participation of the government in environmental issues (Adenle et al. 2015). It requires a whole government effort including excellent planning, creating mass awareness, and meticulous execution of strategies for conservation. The efforts to reduce anthropogenic repercussions on biodiversity have been widely amplified since the first United Nations Convention on Biological Diversity (CBD) was held in 1992. Until now, a total of 196 countries have ratified the legal treaty and devoted themselves to "the conservation of biological diversity, the sustainable use of its components and the fair and equitable sharing of the benefits arising out of the utilization of genetic resources" (https://www.cnd.int). Strategies, frameworks, policies, and action plans have also been developed at international, national, and regional levels by various government and nongovernment organizations to tackle the loss of biodiversity. Developing countries although behind, yet their participation in conservation practices has been continuously increasing. Several conservationists are also adopting cultural and indigenous management practices to protect natural ecosystems from present and future catastrophes (Adenle et al. 2015). Such efforts gain prominence in view of the greater biodiversity in developing countries rather than in developed nations. Despite these many endeavors, biodiversity (especially the wild floral and faunal populations) continues to decline, and the risk of species extinction continues to intensify, thereby threatening all the biotic components of the environment interconnected through a complex food web (IPBES 2019).

Several factors affect the biotic components and natural processes, and unfortunately, most of these are human-driven. Biodiversity loss is usually an unintentional aftereffect of policy verdicts undertaken for economic growth and development. Urbanization, agricultural and infrastructural expansions, increasing domestic and industrial demands, tourism, and illegal trade are the major forces imposing undue pressures on biodiversity (Cardinale et al. 2012, IPBES 2019). The key pressures include habitat loss/fragmentation, invasive alien species, overexploitation of resources, pollution, and climate change (IPBES 2019). New technologies developed to mitigate environmental issues may further affect biodiversity if they do not offer sustainable and integrated solutions. On top of these popular threats, there are several other issues that are not yet well understood such as microplastic pollution, artificial life, etc.

Although abundant information has been collected on the natural/anthropogenic disturbances which affect different life forms, issues and challenges associated with biodiversity are dynamic and so is its ever-changing status. Research in this direction, therefore, needed to be levelled up at every step, and conservation managers are required to stay up to date. Knowledge gaps pertaining to the distribution, population trends, conservation status, and ecological roles of several microbial, invertebrate, and wild plant species need to be filled. In addition, more deep-seated changes, policies, and decision frameworks are required for the conservation of biodiversity, along with an assurance of their effective implementation. Both the traditional and modern conservation approaches—such as ecological restoration, ecotourism, targeted habitat management, habitat creation/re-establishment, trans-boundary conservation, check on invasive species, captive breeding, and reintroduction of species—are needed to be adopted to contain the rate of biodiversity loss (ref). These approaches should also take into consideration the apparently intractable economic and political concerns. Furthermore, it is important to note that biodiversity conservation needs to be holistic in approach with a participatory framework and inclusive of every developed and emerging economy of the world, as global biosphere functions as a whole and any harm to an ecosystem is generally separated on temporal and spatial scales from the ones experiencing its repercussions (Matarrita-Cascante et al. 2019, Smith et al. 2021).

Since conservation of biodiversity and maintenance of ecosystem processes are fundamental for the continued existence of human beings, an improved understanding of factors and processes responsible for declining biodiversity is essential. The present book offers a platform to discuss the status, issues, and challenges associated with biodiversity in the present scenario, particularly in the Indian context. We tried to review major factors that drive biodiversity loss in marine, freshwater, and terrestrial ecosystems and outlined the key efforts put forward by the Government of India to conserve biodiversity. The discussion draws a broad range of individual perspectives across natural sciences from researchers, ecologists, wildlife biologists, and conservation practitioners.

The book comprises 23 chapters, with the first 5 chapters focusing on the biodiversity of lower and higher plants and the next 4 chapters devoted to the biodiversity of invertebrates, herpetofauna, birds, and wild fauna. Similarly, status, issues, and challenges to the freshwater and marine biota, diatoms, are discussed separately in three chapters. A special focus on agricultural crops and livestock, non-agricultural insects, and insects of agricultural importance has been provided in another four chapters. Thereafter, the next two chapters emphasized the rising global issue of biological invasions in terrestrial and aquatic ecosystems. The last few chapters shed a light on specific reasons for biodiversity loss in India and conservation efforts put forward by the Government of India, and the relevant laws for the protection of biodiversity in India have been suitably dealt with. Overall, the book attempts to illustrate the present and potential threats to biodiversity in India across different ecosystems and taxonomic groups.

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Part II
Plant Diversity

Chapter 2
Status, Issues and Challenges of Biodiversity: Lower Plants (Non-vascular)

D. K. Upreti and Rajesh Bajpai

2.1 Introduction

India has a total geographical area of about 329 million hectares with a coastline of over 7500 km. The ecological diversity of the country ranges from sea level to the highest mountainous ranges together with hot and arid conditions in the northwest to cold arid conditions in the trans-Himalayan region, tropical wet evergreen forest in north-eastern India and the Western Ghats, mangroves of Sundarbans and freshwater aquatic to marine ecosystems.

India has 12 biogeographical provinces, 5 biomes and 3 bioregion domains (Cox and Moore 1993). Being a mega-diversity country, India exhibits an exceptional concentration of endemic species in four biodiversity hotspots, namely, eastern Himalayas, Western Ghats (Sri Lanka), North-east India and Andaman Island (Indo-Burma). Forest, grassland, wetlands, coastal, marine and desert are the major ecosystems in India. The forest cover of the country contributes about 21.05% (692,027 km^2) with 16 major forest types comprising 221 subtypes (Champion and Seth 1968). India has about 4.1 million hectares of wetlands, about 6700 km^2, i.e. 7%, of mangroves of the world. Coral reef, a unique marine ecosystem, occurs in Andaman Islands, Lakshadweep Islands, Gulf of Kutch and Gulf of Mannar. The states of Rajasthan, Gujarat, Punjab and Haryana cover about 2% of the total land mass of desert ecosystem, characterized by low precipitation and largely barren arid lands. The Ladakh (Jammu and Kashmir) and Lahaul-Spiti of Himachal Pradesh covers an area of about 109,990 km^2 as cold deserts.

India harbours a total of 45,500 species of plants and ranks among the top ten species-rich nations with high endemism. Among the vascular plants, Angiosperm and Gymnosperms are represented by 18,043 and 74 species, respectively. Among

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the lower group of plants (non-vascular) Bryophytes and Pteridophytes are represented by 2562 and 1267 species, respectively, while Algae, Fungi and Lichens are represented by 7310, 14,883 and 2900 species respectively. Apart from the vascular and non-vascular plants, India is also known for 98 virus and bacteria species. Since the non-vascular plants exhibit a wide variation in their diversity and distribution in India, the issues and challenges regarding their threats and conservation are described separately for each group in the following sections.

2.2 Status of Fungi

Fungi lack photosynthetic capacities and thus obtain their food as saprophytes. Fungi range from single-celled yeasts to mushrooms and moulds to larger slabs of bracket fungus growing up on the treetrunks and branches. Many fungi live properly in soil and water, and many more engage in parasitic or symbiotic relationships with other plants and animals. Most species of fungi are composed of strands of cells called hyphae that combine to form a fungal body or mass known as mycelium. Around 96,000 species of fungi have been described from the world of which about 14,883 species under 45 classes, 120 orders, 345 families and 2660 genera are known from India.

2.3 Status of Algae

Algae are single- or many-celled organisms that have varied size and shape. Algae occur on both land and water and have ability to adopt harsh environmental condition. Algae occur in fresh water of river, pond wetland and lakes together with marine water of salt marshes, salt pans, estuaries and the ocean. Apart from water, algae also grow on stones, rocks, snow surface, thermal springs, acid bogs, alkaline as well as fertile and desert soil in sub-aerial habitats such as tree trunk as epiphytes. Algae play a vital role in the world's ecosystem as a primary producer and also as a source of natural products such as bio-fertilizers and biochemicals. Algae are classified into 11 classes pertaining to Chlorophyceae, Xanthophyceae, Chrysophyceae, Bacillariophyceae, Cryptophyceae, Dinophyceae, Chloromonadineae, Euglenophyceae, Phaeophyceae, Rhodophyceae and Cyanophyceae. India is represented by the occurrence of 7310 species of algae under 10 classes and 95 orders and 2529 genera.

2.4 Status of Lichens

Lichen may resemble a single plant-like organism, but it is really a colony of algae embedded in a matrix formed by the filaments of a fungus and thus is a good example of symbiosis. The algae in lichens make food through photosynthesis, while the fungi absorb food and water from their environment. Owing to its symbiotic nature, lichens can survive in challenging harsh environments of Arctic and Antarctic or dry arid regions. There are about 20,000 species of lichens known so far from the whole world of which India is represented by more than 2900 species belonging to 79 families and 407 genera. Lichens produce a major fodder source for reindeer and caribou and are used commercially as food, spices, dyes and medicines.

2.5 Bryophytes

Bryophytes, commonly called “amphibians of plant kingdom”, are widely spread in almost all the phytogeographical regions of the country. There are three distinct lineages of bryophytes: thalloid/liverworts (Marchantiophyta), hornworts (Anthocerotophyta) or mosses (Bryophyta). In India, the bryophytes are represented by 2562 taxa with 1636 species of mosses, 887 liverworts and 39 hornworts exhibiting their rich diversity in the Himalayas, northeast and peninsular India and Andaman & Nicobar Islands as they prefer to grow in damp and shady sites of these areas.

Bryophytes provide important environment services as they together with lichens help in soil formation and stabilization. Similar to lichens, bryophytes are also an excellent organism for biomonitoring environmental condition of an area.

2.6 Pteridophytes

The land plants evolved 430 million years ago from predominately freshwater green algae. Living members of these groups of plants seem more evolved today. These plants reproduce by means of spores and alternating generations. The reproduction process of ferns is different from the flowering plants. The fern frond or leaf under them bears rows of small brown dots-like structure called the sporangia which inside bear the spores that develop and release into the air. The fallen spore sprout out into tiny heart-shaped plants that anchor themselves in the ground with root-like structure called rhizoid. The heart-shaped plant (gametophytes) bears eggs and develops sperm. The structure bearing sperm swells and bursts due to rain water and releases flagellated sperm that travel to the egg in water and fertilized the egg, thus resulting in an embryo that develops into a new plant (sporophyte).

The fern species thrived on earth from 359 to 299 million years ago during the carboniferous period, which is well-known as age of ferns since they were the dominant vegetation on earth in that period. The ferns that grew during the carboniferous period are now extinct, but some of them likely evolved into the ferns we know today. As many as 12,000 species of ferns have been identified worldwide of which India is represented by 1267 species.

2.7 Challenges to Biodiversity

At present throughout the world, there are a number of factors responsible for the loss of biodiversity, which is occurring at a very alarming rate. A number of conservation programmes are there, but the problem lies in their implementation; thus, there is a great need of public awareness, and changes in the attitude of the people are required. Among the different areas of the earth, the biological diversity in the urban areas is affected greatly and implementation of conservation programmes in these areas is most difficult. The urban areas lack open spaces in inner cities, or they are small and isolated and difficult to maintain as natural ecosystem for earlier resident species of the area.

Human interventions including development activities and rampant poverty are leading to change in land use patterns, habitat loss and fragmentation in the Indian Himalayan regions. In Western Ghats selective logging and conservation to agricultural and cash crop plantations and many river valley projects contributed to the decline of biodiversity. Mass tourism, unsustainable land-use practices and extensive subsistence dependence on the forest are major challenges for loss of both of a large number of faunal and floral elements including lower group of plants.

In India, the implementation of the United Nations Convention to Combat Desertification (UNCCD) indicates that most of Indian arid, semi-arid and dry sub-humid areas are either subject to desertification, identified as drought-prone or considered wastelands. India has 115 wetlands, identified under the National Wetland Conservation Programme (NWCP).

2.8 Reasons of Worry

The fast pace of urbanization together with industrial development in the country affected severely different groups of plants together with a number of lower group (non-vascular) plant species moving towards extinction. Thus, to maintain ecological balance, conservation of non-vascular plant diversity in the country is a prerequisite.

Most of the lower groups of plants excluding fungi and algae are slow-growing organisms. Lichens which are commercially exploited frequently for spices and dyes have growth rates from 5 mm/year to about 2 cm/year. Sometimes the attempts to reintroduce and transplant the species are difficult as certain plant species have their phytogeographical limitation and host specificity. Commercial use of flora by the ethnic people in remote areas is a good source of income for them; however, unscientific exploitation of flora for its commercial use sometimes resulted in the extinction of a number of taxa.

Various developmental activities lead to human influx accompanied by destruction of a number of ecosystems such as habitat loss, fragmentation and degradation through conversion of land use through agriculture, urbanization and industrial development, invasive alien species, and over-exploitation of natural resources including plants and animals which are among the major threats faced globally and in our country. More than 1.17 million hectares of forest land is estimated to have been diverted for more than 23,000 developmental projects since the enactment of the Forest Conservation Act in the year 1980 (MoEF 2008 report). The pressure of livestock grazing forest and grassland together with increasing incidence of forest fires is also a great threat in the dry deciduous forest.

2.9 Conservation Efforts and Strategies

Almost all the lower groups of the plant have insufficient information regarding their status in the IUCN red list categories in the world and also in India. It has been estimated that 15–20% of all plant species would become extinct and 25–30% of the genetic diversity would possibly be lost over the years leading up to the year 2025. The threat of extinction may increase depending upon the increase in human interferences. Protected areas (PAs) are an important element of conservation strategies to preserve tropical forests (Geldmann et al. 2013). India has about 5% of the total geographical area as PA with 448 Wildlife Sanctuaries, 102 National Parks and 18 Biosphere reserves (MoEF 2011).

In the year 2001, the conservation of lower plants was given further importance of the Global Strategy for Plant Conservation (GSPC) as a part of CBD provide a useful structure within which plant conservation work of lower plants and fungi in Scotland was initiated.

The initiation of conservation efforts in a country requires understanding and documentation of the plant diversity of the country/area. A meagre information about the Red data Books (CPCB) regarding the lower group of plants in India is available. The conservation efforts by the Central Government, State Government and local administration and the role of society in maintaining the forest, ecological balance and socio-economic development were realized by National Forest Policy (NFP), and a minimum 33% of country's geographical area under forest and trace cover was maintained. At present, the country has 137 protected areas (PAs) in Indian Himalayan regions and Western Ghats.

The National Biodiversity Action Plan (NBAP) involves the Ministry of Environment Forest and Climate Change (MoEF&CC) and 23 ministries/Government of India Departments, State Forest Department, state planning boards, local-level institutions such as village eco-development committees (VEDCs), joint forest management committees (JFMCs) and Gram sabha (Village assemblies) for implementation of different conservation strategies for conservation of the biodiversity of the country. National Biodiversity targets and Millennium Development Goals (NBT&MDGs) are other efforts toward achieving targets for conservation and human development in the country.

The country is taking significant steps in achieving the 20 Aichi Biodiversity targets which deal with the demands of a growing human population for food, medicine, fibre, shelter and fuel, along with the need for economic development that is increasing the pressure on biodiversity and ecosystem throughout the country.

Under India's fifth report on convention on Biological diversity, the following 12 National Biodiversity targets are proposed:

1. Indicators and monitoring framework: By 2020 a significant proportion of the country's population, especially the youth, are aware of the values of biodiversity and the steps they can take to conserve and use it sustainably.
2. By 2020, values of biodiversity are integrated in national and state planning processes, development programme and poverty alleviation strategies.
3. Strategies for reducing rate of degradation, fragmentation and loss of all natural habitats are finalized and actions put in place by 2020 for environmental amelioration and human well-being.
4. By 2020 invasive alien species and pathways are identified and strategies to manage them developed so that population of prioritized invasive alien species are managed.
5. By 2020 measures are adopted for sustainable management of agriculture, forestry and fisheries.
6. Ecologically representative areas on land and in inland waters, as well as coastal and marine zones, especially those of particular importance for species, biodiversity and ecosystem services, are conserved effectively on the bases of Protected Area (PA) designation and other areas based on conservation measures.
7. By 2020 genetic diversity of cultivated plants, farm livestock and their wild relatives including the socio-economically or agriculturally valuable species is maintained.
8. By 2020 ecosystem services especially those relating to water, human health livelihoods and well-being are enumerated.
9. Access to genetic resources and the fair and equitable sharing of benefits.
10. By 2020 an effective participatory and updated national biodiversity action plan will be made.
11. By 2020 national initiatives using communities and traditional knowledge relating to biodiversity are strengthened, with a view to protecting this knowledge in accordance with national legislation and international obligations.
12. By 2020 opportunities to increase the availability of finance, human and technical resources to facilitate effective implantation of the strategic plan for

biodiversity 2011–2020 and the national targets are identified and the strategy for resource mobilization is adopted.

2.10 Conservation of Fungi

The fungi are the largest group of organisms on the earth next to insects. Fungi are different from animals and plants and belong to a separate biological kingdom. Fungi are also threatened by climate change, habitat destruction, invasive species, pollution and over-exploitation; therefore, the conservation of fungi is also important similar to another organism. Following the IUCN protocol for conservation of fungi, the Agharkar Research Institute (ARI), Pune Department of Science and Technology (DST), set up in the year 2008 the National Facility of Culture Collection of Fungi (NFCCF) with the aim to conserve the germplasm of indigenous fungi in a repository. NFCCF is holding over 2800 strains of fungi together with 9000 herbarium samples.

2.11 Conservation of Lichens

The Indian Himalayan regions and Western Ghats in south India together with Andaman Island exhibit occurrence of most of the endemic lichen taxa in India. The central Indian region particularly the region of Amarkantak-Achanakmar Biosphere also represents occurrence of some unique lichen taxa being a meeting place of elements coming from Indian Himalayan regions and south India.

Upreti and Nayaka (2008) suggested creation of lichen gardens and lichen sanctuaries in the country for conservation of lichens. Most of such sanctuaries proposed are already protected in a number of protected areas of the country in wildlife sanctuaries, national parks and biosphere reserves.

2.12 Conservation of Algae

According to IUCN (2003), a single marine red alga *Vanvoorstia bennettiana* (Delesseriaceae, Ceramiales) was assessed as extinct in the red list. The red list of algae in Japan includes 5 extinct species (single species extinct in wild) and 35 critically endangered.

For algae, in situ conservation involves the maintenance of genetic variation at the locations where it is conducted either in the wild or in traditional farming systems. The establishments and scientific management of nature reserves in different part of the country especially restoration of degraded habitats would be helpful in this purpose. Under the ex situ conservation, the algal samples are conserved either as living collections (e.g. culture collections) or as spores, and DNA are maintained under special artificial conditions. Cryopreservation allows living algae to be maintained indefinitely in an assessed state.

The culture collection methods for algal conservation have several advantages as they are efficient and reproducible and feasible for short-, medium- and long-term storage.

Cryopreservation is storage of living organism or a portion thereof at an ultra-low temperature, and it remains capable of survival upon thawing. Hundreds of species of cyanobacteria and eukaryotic microalgae have been successfully cryopreserved.

2.13 Conservation of Bryophytes

Bryophytes are the second largest group of land plants after angiosperms. Bryophytes have not been figured as largely as flowering plants in conservation initiatives. Recently the importance of ex situ conservation and the value of in vitro biotechnology have been endorsed in the conservation of biological diversity and in the subsequent global strategy for plant conservation. The bryophyte flora is continually being impoverished in many countries today. The red list that has already been published shows that the rate of confirmed extinction among bryophytes ranges, in most cases, from 2 to 4% and that a substantial proportion of the bryoflora worldwide is threatened in the short term. However, the level of legal bryophyte protection and interest varies from region to region. Interest in bryophyte conservation has increased significantly in the last two decades especially in developed countries. The ex situ conservation of bryophytes consists of several equally important steps: collection of material, propagation and storage, cryopreservation and reintroduction. The availability of material of threatened species is limited by rarity and legislation. The collection of plant material should respect natural populations and avoid potentially adverse impacts on them due to harvesting in situ. However, in propagation phase it is normal to use axenic cultures. In bryophytes, developing in vitro and ex situ propagation and cryopreservation techniques for both vegetative tissue and spores provides additional security against the permanent loss of bryophyte diversity. The focus on rapidly declining and extremely rare species must be a top priority. Once we lose the species, we lose them forever.

2.14 Conservation of Pteridophytes

Pteridophytes prefer moist tropical to temperate habitats and thus are known to occur from sea level to the highest mountains. India having its diversified topography, variable climatic conditions and unique geographical position exhibits the presence of several migrant species. The pteridophytes prefer to grow in moist shady places and are dependent on the microclimatic condition of the region. The disturbance or any change in the microclimate influence the population of these plants up to a great extent. The population of pteridophyte species in a particular area is greatly influenced by deforestation, thinning out of forests and reduction of moisture and shade, increasing urbanization, industrialization encroachment of forest lanes, unplanned development activities and climate change.

The unplanned felling of trees in the forest is responsible for the reduction in the epiphytic pteridophytic species. Large-scale collection of ferns from the forest area for ornamental purposes together with for use as medicine or food (vegetable) also poses a threat to the fern and fern allies.

The conservation of flowering plants has been achieved up to a greater extent in the country; however, regarding the conservation of Pteridophytes, few fern conservatories or fern gardens are established in the country at CSIR-National Botanical Research Institute, Lucknow, and CSIR-Institute of Himalayan Bioresource Technology, Palampur. For conservation of RET species of pteridophytes, the tissue culture is a useful technique for mass multiplication of the species within a short time and a number of such species and regenerated in vitro in the country. Apart from in-vitro propagation, localities rich in pteridophytic species must be declared as "Pteridophytic biosphere reserve" such as Pachmarhi, Madhya Pradesh.

Apart from Botanical Survey of India and few other governmental organizations, CSIR-National Botanical Research Institute, Lucknow, Uttar Pradesh, is one of the well-known scientific organizations playing vital roles in the conservation of Algae, Lichens, Bryophytes and Pteridophytes in the country. The institute has excellent repositories of all the non-vascular plants represented by more than 150,000 specimens of lichens, 15,500 of Bryophytes, 2500 of algae and 6500 of Pteridophytes of herbarium specimens.

Apart from rich and widely represented herbarium specimens from different parts of the country, the institute has more than 20 living threatened specimens of bryophytes in the moss garden of the institute together with more than 65 species of ferns and fern allies in the fern house.

2.15 Recommendations

The most urgent task for the conservation initiative regarding lower group of plants in the country needs understanding and documenting diversity of different non-vascular plants. Through red list species that is selection of species in need of conservation (RET species) and to target the preparation of distribution database and identify data gap, continue further field survey. Importance should be given to identification of species of principal importance for conservation, based on the grouping of habitat-specific species: general habitats (natural, woodlands, wayside, trees, park, etc.). Specific habitats different forest/Montage lime stone/mangrove/ boulders. Sub littoral water/fresh water pond/snow beads for Bryophytes/Lichens/ Pteridophytes. It is also recommended that there should be the promotion of the survey of habitat of high nature conservation interest for their lower plants. Sites that currently lack statutory protection should be recognized as important for their lower group of plants' interest.

There are a number of sites that should urgently be designated for their lower group of plants that they can receive adequate protection and funding support for monitoring and appropriate management. Some of such sites are core zones of most of the biosphere reserves, different forest types, coastal sites for mangrove lichens and other palmate trees and specified freshwater lake in different phytogeographical regions.

Sustainable use of biodiversity is one of the three pillars of successful conservation. Different lower group of plants collected majority for seaweed collection for algination/food/biofuel/biofertilizer (Algae), spices/dyeing material/medicinal (Lichens), horticulture trade (Bryophytes), food/medicinal (Fungi) and ornamentals/medicinal (Pteridophytes) and the sustainable harvesting of the lower group of plants can be maintained/regulated by code of conduct to inform the local collectors.

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Chapter 3
Status, Issues and Challenges of Biodiversity: Higher Plants

S. S. Dash and A. A. Mao

3.1 Introduction

India lying between 8°45′ and 37°6′ N latitude and 68°51′ and 97°25′ E longitude, encompassing an area of about 329 million hectares, has been recognized as one of the world's 17 megadiverse countries (Mittermeier et al. 1997). Situated at the tri-junction of Afro-tropical, Indo-Malayan and Paleo-Arctic realms, the country has all possible types and extremities of climates suitable for supporting a wide array of ecosystems and habitats. It demonstrates both extremes from rainless hot deserts of Rajasthan or cold deserts of Ladakh to the highest rainfall region of the world in Meghalaya; from hot, humid tropical rainforests of Western Ghats to coldest coniferous forests of eastern Himalaya; riverine or shola grasslands of Kerala to alpine grasslands of western Himalayas; and warm mangrove coastlines to icy mountains. The altitude varies from the sea level to the highest mountain ranges of the world. This broad range of land systems, different climatic zones, long geological history and the extreme diversity of habitats have contributed immensely to the extraordinarily rich floristic diversity of India. India has only 2.4% of the total geographical area of the world, but harbours nearly 8% of the globally known floral species (Mao and Dash 2019), of which 28% are endemic to the country (Singh et al. 2015). The Indian flora is concentrated in four floristic hotspots: viz. (1) Indo-Burma covering Mizoram, Manipur, Nagaland, Meghalaya, Tripura and Andaman Islands; (2) Himalayas covering the states of Jammu and Kashmir, Himachal Pradesh, Uttarakhand, the northern part of West Bengal (Darjeeling), Sikkim, the northern part of Assam and Arunachal Pradesh; (3) Western Ghats covering the states of Tamil Nadu, Kerala, Karnataka, Goa, Maharashtra and Gujarat; and (4) the Sundaland covering the Nicobar Islands, which are identified amongst the 36 'global bio-diversity hotspots' (Myers et al. 2000; Mittermeier et al. 2005).

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India's biodiversity is not evenly distributed across the different regions. The pattern of species richness of Indian flora, its distribution and its affinities may be attributed to its historical processes and major geological events (Jetz et al. 2004). The supercontinent Gondwana landmass started to disperse between 170 and 180 million years ago; India was the first to break away, followed by Africa and then New Zealand, which started to move towards the north. By the end of the Late Cretaceous period (65 million years ago), it collided with the Eurasian mainland, of northern hemisphere, resulting in the rise of the mighty and lofty Himalayas. Pronounced global warming also took place during the Paleocene-Eocene period, when India collided with Asia causing significant changes to ecological and environmental factors, which had a profound effect on Cenozoic topography and floral turnover. This had also created a corridor that possibly served as a biotic link between India, Asia, Europe and Africa, giving rise to new ecological opportunities in interchange of the Indo-Eurasian elements and simultaneously isolation of Gondwana elements in the southern peninsula. The occurrence of several plant groups such as the *Rubus*, *Exbucklandia*, *Aspidocarya*, *Laurels*, etc. in parts of Europe and Asia supports this theory (Chatterjee and Bajpei 2016).

The structure, composition and function of many plant communities of Indian flora are greatly governed by physiographical characters such as climatic, geographic position, evolutionary history and taxonomic affinities. Physiographically, India can be divided into three major divisions: (a) the peninsula, (b) the extra-peninsula and (c) the North Indian alluvial plains. Location-wise, the peninsula is a triangular plateau bordered by the Vindhyan ranges in the north; extra-peninsula at the northern extremity of the country constitutes the lofty Himalayan and other mountains, while the third division, the alluvial plains, exists in between the peninsula and the extra-peninsula region comprising extensive plains of Assam, West Bengal, Bihar, Uttar Pradesh and Punjab (Murty et al. 1996). Based on a study of the distinctive biogeographic characteristic features of the country from north to south and east to west, 10 biogeographic zones and 24 biotic provinces (Fig. 3.1, Table 3.1) have been identified (Rodger et al. 2000).

3.1.1 Phytogeographical Affinities of Plants: Indian Context

India's biota has a diverse origin that comprises resident lineages of varied antiquity and immigrants that have arrived and settled at different times. As a result, the floristic elements were then subjected to further divergence and contributed to the pattern of diversity that we see today (Singh and Dash 2018). It is assumed that the floral elements of north-western Himalayas are common with Mediterranean, West Asian and Central Asian regions; Western Indian elements are common with the eastern parts of Africa; and plants of southern Western Ghats are common to Sri Lanka and even to distant Australia. The flora of north-east India has been considered common to Tibet, China, Japan, Indo-China, Myanmar, Thailand and Malesia, while the floral elements of Andaman and Nicobar Islands show close affinity to the

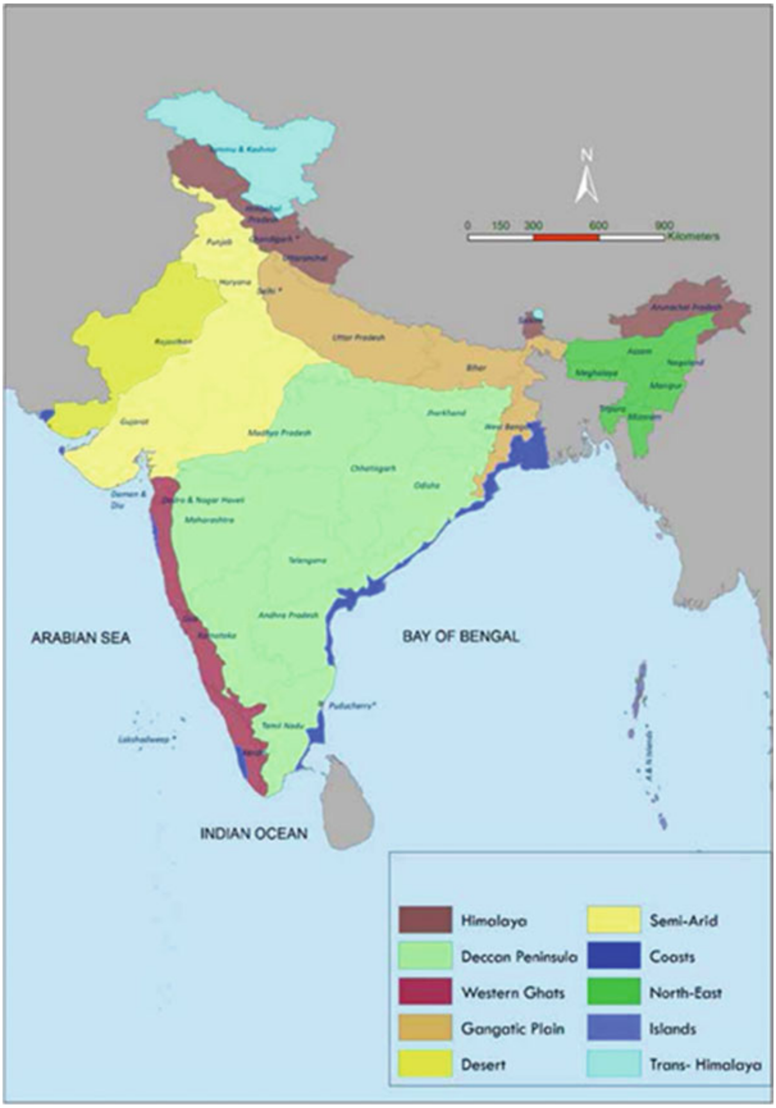

Fig. 3.1 Biogeographic zones of India (source FSI)

flora of Myanmar, Thailand, Indonesia, Sumatra and Java. These migratory elements got mixed up with the indigenous elements of India to produce the present-day complex plant diversity. The occurrence of many species that are reported within India and other disjunct members from *Codonopsis*, *Clethra*, *Aspidopterys*, *Archidendron*, *Elaeocarpus*, *Schima*, etc. reflects processes of contraction and isolation of formerly widespread taxa (Tribsch and Schönswetter 2003) (Table 3.2).

Table 3.1 Phytogeographic regions of India

Biogeographical zone	Provinces	State covers	Percent of total land area
Trans-Himalaya	Ladakh mountain	Parts of Jammu and Kashmir	3.3
	Tibetan plateau	Upper ridges of Himachal Pradesh	2.3
Himalaya	Northwest Himalaya	Himachal Pradesh, Uttarakhand	1.6
	Central Himalaya	Sikkim	0.2
	Eastern Himalaya	Arunachal Pradesh	2.5
Desert	Thar	Rajasthan	5.4
	Khacha	Gujarat	1.1
Semiarid	Punjab plains	Punjab, Haryana and Rajasthan	3.7
	Gujarat and Rajputana	Rajasthan, Gujarat and parts of Madhya Pradesh	12.9
Western Ghats	Malabar plains	Maharashtra, Karnataka and Kerala	2.0
	Western Ghat mountains	Maharashtra, Karnataka and Kerala	2.0
Deccan peninsular	Central highlands	Madhya Pradesh	7.3
	Chota Nagpur	Jharkhand, Chhattisgarh and Western Odisha	5.4
	Eastern highlands	Southern Odisha and Northern Andhra Pradesh	6.3
	Central plateau	Maharashtra, Andhra Pradesh and parts of Karnataka	12.5
	Deccan south	Andhra Pradesh, Karnataka and Tamil Nadu	10.4
Gangetic plains	Upper Gangetic plain	Uttar Pradesh	6.3
	Lower Gangetic plain	Bihar and West Bengal	4.5
Coasts	West coast	Coastal region of Gujarat	0.6
	East coast	Coast of West Bengal, Odisha and Andhra Pradesh, Tamil Nadu	1.9
	Lakshadweep	Lakshadweep	<0.1
North east	Brahmaputra valley	Assam	2.0
	Northeast hills	Manipur, Meghalaya, Tripura, Nagaland, Mizoram	3.2
Islands	Andamans	Andamans	0.2
	Nicobars	Nicobars	0.1

After Rodger et al. (2000)

Table 3.2 Phytogeographic affinities of Indian flora and major elements

Major elements	Affinity	Areas/localities
Afro-Perso-Arabian/Western elements	Malesia and Polynesian islands	Estuarine and tidal mangrove zones of Sundarbans and Coromandel coast
Indo-African elements	Tropical African and Mediterranean regions The Sudan and South West Arabian elements	Desert of Thar, extending into Rajasthan, the Punjab, parts of Uttar Pradesh and north Gujarat, Rajasthan and Kutch
SE Asian-Malaysian element	Myanmar, Malayan peninsula and Indonesia	Warm broadleaved and subtropical forests of India Andaman Islands
Himalayan-Chinese-Japanese elements	Subtropical and temperate Southeast Asia	Temperate and subtropical ancient biota with high endemism found in entire Himalaya. Based on the range of distribution limit both east- and westward, six minor groups have been categorized
Tibetan elements	Tibetan plateau, China	Xerophytic elements in higher elevations of Himalayan states
Euro-Siberian elements	European and Siberian origin	Temperate and alpine zone species of Arunachal Pradesh, Sikkim and Jammu and Kashmir
Artic-Alpine elements	High mountain ranges of Europe and Asia	Higher ridges of Himalaya

3.2 Endemism in Indian Flora

Occurrence of high endemic species, their concentration and the level in the biological hierarchy are not only important factors for judging the phytogeographic affinities but also are suggestive of isolation, the centre of speciation, extinction and adaptive evolution of the biota in that region (Nayar 1980). Similar to oceanic islands, the Indian flora can also be considered to be isolated from other regions by high mountain ranges in the north; by large water mass in the southern, eastern and western regions; and by extremely arid conditions in the north-western regions preventing outbound migration of species resulting in the evolution and speciation of several endemic elements (Fig. 3.2).

As per the present estimate, there are about 4603 vascular plant taxa (angiosperms) belonging to 1008 genera, and 154 families are recorded as strictly endemic to India (Singh et al. 2015; Dash et al. 2009; Mao and Dash 2019). Of the total endemics, dicotyledon represents 72% and monocotyledon 26%. However, these numbers are dynamic; perhaps it would be necessary to revise these figures at least once in 3 years or after the revision of the entire flora of India. Endemic plants in India are largely concentrated in four major biogeographical zones, viz. the Western Ghats (about 2116 taxa), eastern Himalayas and north-east India (about 861 species), northwest and western Himalayas (about 297 taxa species) and Peninsular India (about 312 species). The Andaman and Nicobar Islands contribute about 278 endemic taxa, while the Eastern Ghats contribute 166 taxa. The flora of the Indian region has no endemic families; however, there are about 58 endemic genera,

Paphiopedilum hirsutissimum (Lindl. ex Hook.) Stein: en endemic to eastern Himalaya

Stapletonia arunachalensis P. Singh, S.S. Dash & P. Kumari: An endemic to Arunachal Pradesh

Fig. 3.2 Photographs of two endemic plant species of India

out of which 49 genera are confined to Peninsular India (Singh et al. 2015). The recent new discoveries of plants and their new distributional records in India revealed a considerable decline of endemic genera from the earlier reports (Nayar 1996; Ahmedullah 2000; Mitra and Mukherjee 2007; Mao and Dash 2019) because majority of the genera which were earlier considered as endemic to India also occur in the adjacent countries like Bhutan, China, Myanmar, Nepal, Pakistan and Sri Lanka. Depending on the concentrations of endemic plants, the following major and minor centres of endemism are recognized in India (Singh et al. 2015; Table 3.3).

3.3 Ecosystem Diversity of India

The vast geographic area with its diverse climatic conditions and topography has given rise to all types of ecosystems. The varied ecosystems, viz. forest, grasslands, mountain ecosystems, riverine and aquatic ecosystems, have produced all possible types of vegetations, such as tropical, subtropical, temperate and alpine, humid evergreen rain forests, semi-deciduous and deciduous forests, scrub jungles, hot dry arid zones, cold dry arid zones, coastal mangroves, submerged seaweeds and seagrasses, salt marshes, swamps, sand-dune formations, fresh water and saline aquatic vegetations, etc. in India. Each of these ecosystems having further been classified as biotypes and communities is characterized by unique floristic composition and highly influenced by the elements of adjacent phytogeographical regions.

3.4 Forest Ecosystems

Among terrestrial ecosystems, forest and vegetation are important components of land cover and a climatic expression of biodiversity in terms of spatial coverage. The total forest cover of India is about 21.67% (712,249 km^2) of its geographical area

Table 3.3 Major and minor centres of endemic plants (flowering) in India

Major centres	Divisions	Minor centres of endemics
Himalayas	Western Himalaya	Trans/North Himalaya (including Ladakh Himalaya)
		Central Himalaya (including Garhwal and Kumaon)
	Eastern Himalaya	Sikkim Himalaya (including Darjeeling Himalaya)
		Arunachal Pradesh
Peninsular India	Northern Western Ghats	Konkan and Raigad-Khandala Hill complex
		Shimoga-Chikmagalur-Dakshin Kannada of Karnataka
	Southern Western Ghats	Malabar coast and Northern Kodagu
		Nilgiris-Wayanad-Silent Valley plateau and hill complex
		Palni hills
		Annamalai and High Range hill complex (including Cardamom hills)
		Agasthyamalai-Tirunelveli and Mahendragiri hill complex
	Deccan	North and South Deccan
	Eastern Ghats	Vishakhapatnam-Arku-Koraput-Jeypore-Bastar track (including Sileru valley)
		Taptapani-Gajapati-Kalinga Track
		Tirupathi-Cuddappa-Nallamalai hills
		Shevaroy-Kollimalai hill complex
North-east India		Assam-Bhramputra Plain
		Khasia-Jaintia hills complex
		Patkai Naga-Lushai hill complex
Islands		Andaman group of islands
		Nicobar group of islands
Central and Western India (extra-peninsular region)	Central India	Rajmahal hills and Chota-Nagpur plateau
		Satpura-Mahadeo-Maikal range
	Western India	Kathiawar-Kutch
		Rajastan-Aravali hills complex

(ISFR 2019). In terms of density classes, area cover by very dense forest is 3.02% (99,278 km^2), moderately dense forest is 9.38% (308,472 km^2) and that of the open forest is 9.26% (308,499 km^2) (ISFR 2019). The state of Mizoram has the maximum forest covers (85.41%) followed by Arunachal Pradesh (79.63%) and Meghalaya (76.33%); however, in terms of total geographical area with forest, Madhya Pradesh has a maximum area (77,482 km^2) followed by Arunachal Pradesh (66,688 km^2) and Chhattisgarh (55,611 km^2). Among union territories, the forest cover of Andaman and Nicobar Islands is 81.74% of its geographical area, while in Lakshadweep it is 90.33%. Based on the parameters such as altitude, community structure, floral composition and habitat conditions, the forest types can be summarized under each phytogeographical region, unique in their composition and characterized by a few typical elements significant to that region. The forest cover in different forest types of India is given in Table 3.4 (Champion and Seth 1968; State of forest report 2019) (Fig. 3.3).

Table 3.4 Forest types of India and their composition

S. No.	Vegetation type	General composition	Area in km^2 (approx.)	% of forest cover
1	Tropical wet evergreen forests	Dense tall forests, entirely evergreen or nearly so	20,054	2.61
2	Tropical semi-evergreen forests	Dominants include deciduous species but evergreens predominant	71,171	9.27
3	Tropical moist deciduous forest	Dominants mainly deciduous but sub-dominants and lower story largely evergreen top canopy even and dense but 25 m high	135,492	17.65
4	Littoral and swampy forest	Mainly evergreens of varying density and height but always associated predominantly with wetness	5596	0.73
5	Tropical dry deciduous forest	Entirely deciduous or nearly so top canopy uneven rarely over 25 m high	313,617	40.86
6	Tropical thorny/scrub forests	Deciduous with low thorny trees and xerophytes predominant top canopy more or less broken, less than 10 m high	20,877	2.72
7	Tropical dry evergreen forest	Hard leaved evergreen trees predominate with some deciduous emergent often dense but usually under 20 m high	937	0.12
8	Subtropical broadleaved hill forests	Broadleaved largely evergreen high forests	32,706	4.26
9	Subtropical pine forests	Pine associated predominates	18,102	2.36
10	Subtropical dry evergreen forests	Low xerophytic forest and scrubs	180	0.02
11	Montane wet temperate forests	Evergreen without coniferous species	20,435	2.66
12	Himalayan wet/moist temperate forests	Evergreen forests mainly sclerophyllous oak and coniferous species	25,743	3.35
13	Himalayan dry temperate forests	Coniferous forests with sparse xerophytic undergrowth	5627	0.73
14	Sub-alpine forests	Stunted deciduous or evergreen forests, usually close formation with or without confers	14,995	1.96
15	Moist alpine	Low but often dense scrub of evergreen species	959	0.13
16	Dry alpine	Xerophytic scrub in open formation mostly of deciduous in nature	2922	0.38

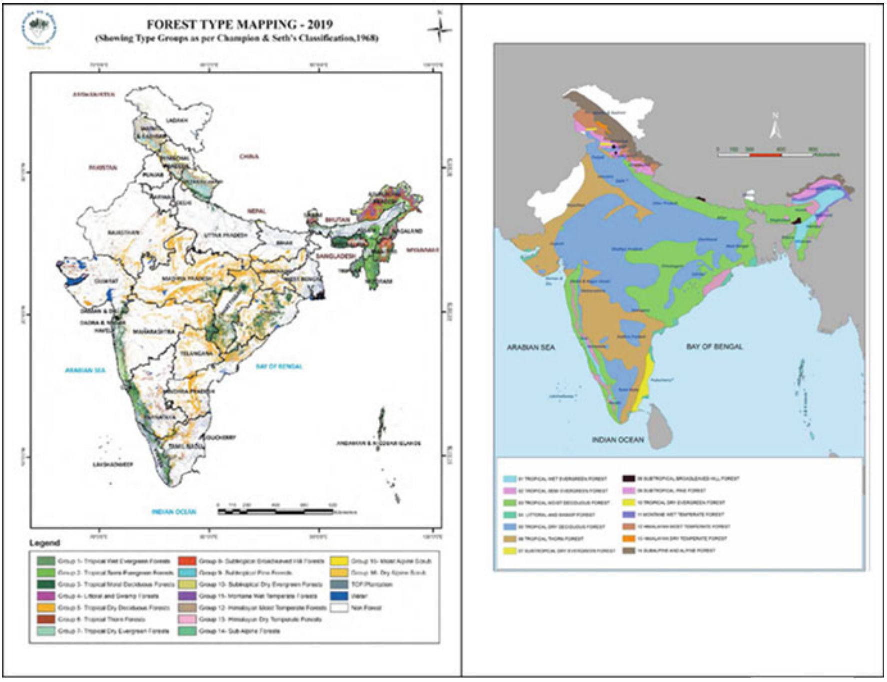

Fig. 3.3 Map showing major forest types of India. (*Source*: FSI)

3.5 Grassland Ecosystems

View of a sloppy Grassland of Uttarakhand

Grasslands are another kind of dynamic ecosystem of its own exhibited by a wide range of ecological characteristics. Alpine grasslands above the tree limits of western Himalaya are locally called as ‘Bugyal or Khark’ (Uttarakhand), ‘Thaach’ (Himachal Pradesh) and ‘Margs’ (Jammu and Kashmir). They play an important role in the pastoral economy and of the local inhabitants. ‘Chaurs’ of the central Himalayan foothills; ‘Terai’ on the Gangetic and the Brahmaputra floodplains; ‘Phumdis’ of Manipur; ‘Banni’ and ‘Vidis’ of Gujarat; grasslands on Pachmarhi plateau; valley *grasslands* in the *Satpuras* and Maikal hills; and ‘shola’ of Western Ghats are some of the unique grasslands of India (Chandran 2015) also play an important ecological role and services.

The most dominant grass species found in alpine grasslands of western Himalaya is *Danthonia cachemyriana*, which provides nitrogen-rich fodder to grazing livestock and sheep, intermixed with cushion-formed members of *Poa*, *Festuca*, *Bromus*, *Agrostis*, etc. Gregarious patches of medicinal plants often flanked with scrubs of *Rhododendron anthopogon*, *Cassiope fastigiata*, *Impatiens sulcata*, *Primula denticulata*, *Saussurea*, etc. are also common on gentle slopes. The riverine plain grasslands in the foothill valleys of Brahmaputra, Lohit and Subansiri in Arunachal Pradesh and Assam are among the tallest in the world. Characteristic species in these highly productive grasslands include *Saccharum spontaneum*, *Phragmitis* spp., *Arundo donax*, *Imperata cylindrica*, *Andropogon* spp. and *Aristida adscensionis* (Singh et al. 2019). The central Indian grasslands regarded as the migratory corridor between Western Ghats and the Himalayas are dominated by *Mischanthus nepalesis*, *Pennisetum*, *Danthonia cachemyriana*, *Arundinella nepalensis* etc. While the shola grasslands are dominated by *Eulalia phaeothrix*, *Dichanthium polyptychum*, *Chrysopogon hackelii* and members of *Agrostis*, *Andropogon*, *Arundinella*, etc., intermixed with gregarious patches of *Strobilanthes*, *Desmodium*, etc.

3.6 Desert Ecosystems

View of a Cold desert in Lahul (photo credit A.N.Shukla)

Deserts are the harsh fragile ecosystems characterized by great diurnal fluctuations and dry or scant rainfall. Two types of deserts, i.e. cold and hot deserts, are found in India with two extremities of floral diversity and adaptation. Cold deserts are found in Ladakh Union Territory; Lahaul, Spiti and Kinnaur in Himachal Pradesh; and Nelang, Mana and Niti valley in Uttarakhand. These are trans-Himalayan rain shadow zones of western Himalayas prevailing between 4500 and 6000 m altitude and characterized by extremely low temperature (−45 °C) and low rainfall. The vegetation of the region exhibits a number of ecological, morphological and physiological adaptations such as cushion-forming habit (*Acantholimon lycopodioides, Thylacospermum caespitosum, Arenaria bryophylla* and species of *Astragalus, Androsace, Draba, Sedum, Saxifraga*); diminutive or miniature habit (*Pleurogyne brachyanthera, Gentiana thomsonii, Taraxacum bicolor, Astragalus heydei, Corydalis crassissima, Thermopsis inflata, Dracocephalum heterophyllum*); bushy habit (*Caragana pygmaea, Ephedra gerardiana, Hippophae rhamnoides, Myricaria prostrata* and *Lonicera hispida*); protective layer of hairs (*Astragalus munroi, Saussurea gossypiphora* and *Soroseris glomerata*); etc. (Shukla and Srivastava 2015).

Hot deserts are found in Rajasthan, Gujarat, South-West Punjab, Haryana and part of Karnataka with one of the most unique ecosystems. More than 670 species of seed plants belonging to 315 genera and 78 families are distributed in deserts. *Calligonum polygonoides*, *Haloxylon salicornicum*, *Capparis decidua*, *Ziziphus nummularia*, *Lycium barbarum*, *Acacia senegal* and *Prosopis cineraria* are some of the dominant tree species, while *Tephrosia falciformis*, *T. purpurea*, *Tribulus longipetalus*, *Cleome vahliana* and are the common shrubs. Some of the common grasses which play a great role in conservation of soil as soil binders are like *Cenchrus ciliaris, Cymbopogon jwarancusa*, *Desmostachya bipinnata, Dichanthium annulatum, Erianthus munia, Lasiurus sindicus, Panicum antidotale, Panicum turgidum,* and *Saccharum munja.* The Indian desert hosts 6.4% endemic plant species such as *Salvadora oleoides*, *Maytenus emarginatus*, *Tecomella undulata*, *Aerva javanica*, *Citrullus colocynthis*, *Crotalaria burhia*, *Dipterygium glaucum*, *Farsetia hamiltonii*, *Indigofera argentea*, *Indigofera cordifolia*, *Indigofera linifolia, Leptadenia pyrotechnica*, *Melhania denhamii*, etc., many of which have high commercial value. The species which strive well in saline habitats are *Cressa cretica*, *Haloxylon recurvum*, *Portulaca oleracea*, *Salsola baryosma*, *Sesuvium sesuvioides*, *Suaeda fruticosa, Tamarix indica*, *Trianthema triquetra*, *Zaleya govindea*, *Zygophyllum simplex*, etc. The different plant communities such as *Dichrostachys cineraria-Parkinsonia aculeata-Prosopis juliflora community*, *Acacia albeda-Prosopis cineraria-Tecomella undulata* or *Acacia nubica-Acacia tortalis-Colophospermum mopane* have proved successful in sand dune stabilization and play a great role in easing desertification. Similarly, *Calligonum polygonoides* and *Leptadenia pyrotechnica* are extremely useful in retaining the soil moisture in low rainfall area. The flora of both the deserts is unique and represented by floral elements which have undergone great evolutionary changes. The vegetation also represents a wide range of wild relatives of cultivated plants with economic potential. The role of desert plants is important in order to restore degraded land, stabilize soil erosion, support agriculture, strengthen food security, safeguard water reserves, combat desertification and enhance the well-being of local people.

3.7 Himalayan Ecosystems

View of typical western Himalaya ecosystem in Himachal Pradesh (enroute to valley of flowers) Photo credit: Dinesh Singh Rawat

The Indian Himalayan Region stretching over 3000 km length uninterrupted and between 80 and 300 km in width forms the northern boundary of the country. These vast mountain ranges spread over the states of Himachal Pradesh, Jammu and Kashmir and Uttarakhand (western Himalaya); Arunachal Pradesh, Sikkim Darjeeling of West Bengal (eastern Himalaya); and Manipur, Meghalaya, Mizoram, Nagaland, Tripura and a part of Assam (North-eastern Hills). The distinctive land features of the Himalayas produced a characteristic climate of its own and have possessed almost all possible forest type ecosystems of India (Dash and Singh 2017). Based on the elevation and climate, the region is demarcated into tropical, subtropical, temperate and alpine ecosystems. Variation in species richness in each of these representative communities is determined by the local topography, altitude, precipitation, temperature and soil conditions. Some of the important plant communities in temperate ecosystems of Himalayan are noteworthy to mention. In eastern Himalaya, these ecosystems are characterized by the mixed population of *Tsuga-Pinus-Taxus* series of conifers with Rhododendron species. *Tsuga-Abies-Rhododendron* in West Kameng district of Arunachal Pradesh, pure stands of *Cupressus* in Upper Siang of Arunachal Pradesh, *Abies-Taxus* in West Siang or *Picea-Larix-Abies* in West Kameng, Tawang districts of Arunachal Pradesh and Dombyeng valley of North Sikkim are typical in nature and not found anywhere in Himalaya. In western Himalaya, pure stands of *Cupressus torulosa* or *Quercus-Abies* community are common between 2200 and 3200 particularly in Uttarakhand and Himachal Pradesh.

The abundance of *Rhododendron* is more in eastern Himalaya, while the abundance of *Quercus* is more in western Himalaya.

Recent studies revealed that a total of 11,157 taxa of flowering plants belonging to 2359 genera under 241 families occur in Indian Himalayan Region (Singh et al. 2019), which amount to about 50% of the total taxa in India. The family Poaceae is represented by maximum number of taxa with 912 species followed by families Asteraceae (820 species), Orchidaceae (819 species), Leguminosae (434 species), etc. *Carex* with 183 species is the most dominant genus in Himalaya followed by *Impatiens* (122 species), *Rhododendron* (112 species), *Primula* (99 species), *Pedicularis* (92 species) and *Saxifraga* (86 species). The Himalayan ecosystems are rich not only in plant diversity but also in a large number of wild relative crop plant genetic resources. Western Himalayas has contributed wild relatives of many edible fruits as *Pyrus, Prunus, Rubus* and *Ribes* and also commercial crops, viz. *Elymus, Eremopyrum, Avena, Allium, Lepidium, Carum, Linum, Cicer*, *Cucumis*, etc., while Eastern Himalaya is the source of wild relatives of *Musa, Elaeocarpus, Morus, Coix, Oryza, Vigna, Trichosanthes, Momordica, Cucumis, Solanum, Brassicaceae, Piper, Amomum, Curcuma, Zingiber and Saccharum.*

3.8 Aquatic Ecosystems

The aquatic ecosystems of India cover from high-altitude Himalayan lakes, to floodplains of the major river systems, saline and temporary wetlands of the arid and semi-arid regions to coastal wetlands such as lagoons, backwaters and estuaries, mangrove swamps and marine wetlands. The ecosystems support a great deal of wetland biodiversity which is almost 10% of the country's total seed plant diversity. The freshwater aquatic ecosystems supporting a wide array of biodiversity are the most productive ecosystems providing great services to human welfare. The coastal ecosystems include estuaries, mangroves, lagoons, seaweeds and seagrass meadows.

Mangrove forests are spread over an area of 4975 km^2 in India (0.15% of the total geographic area). Of these, Sundarbans in the West Bengal has the largest cover (42%), followed by coastal Gujarat (23%) and Andaman and Nicobar island (12%). The three areas alone occupy 77% of the mangrove cover of India (FSI 2019). The mangrove vegetation presents mostly in the inter-tidal region and supports about 44 true mangrove plant species, 86 mangrove-associated plant species and 11 seagrasses. They not only protect the coastal region against erosion, storm surges and tsunamis but also provide many services, commodities and livelihoods to the coastal human communities as the collection of honey, tannins and wax or fishing. Some of the important species of mangrove ecosystems in India are *Avicennia officinalis, Bruguiera cylindrica, Ceriops decandra, Excoecaria agallocha, Heritiera littoralis, Morinda citrifolia, Rhizophora mucronata, Phoenix paludosa*, *Sonneratia alba, Xylocarpus moluccensis*, etc. (Kathiresan 2018; Panigrahy et al. 2012). Seaweed and seagrass ecosystems comprise about 980 macro marine algae (Rao and Gupta 2015) and 14 species of seagrasses. These systems not only provide food and breeding habitats for many organisms including migratory birds but also play a significant role in the coastal livelihood generation and contribute substantially to carbon sequestration (CMFRI 2018).

3.9 Floristic Diversity (Status in Terms of Number and Diversity Indices)

Current estimation revealed that a total of 21,558 taxa of seed plants occur in India under 268 families and 2744 genera. Overall representation of the dicotyledons group is 76% of the total taxa occurring in India. The dicotyledons represented 83% of the total family, 78% of total genera and 75% of total species found in India. There are 1404 cultivated taxa, of which dicotyledons represented 85% while monocotyledon is only 15%. A total of 1907 infraspecific taxa have also been recorded from India, of which 1518 varieties, 337 subspecies and 52 forma are included. Over 60 families of flowering plants are monotypic represented by one species in India like Turneraceae, Illiciaceae, Ruppiaceae, Tetracentraceae, etc. The group-wise current status of plants known from India is given in Table 3.5.

Poaceae with 1480 taxa and 247 genera is the most dominating family followed by Leguminosae (1292 taxa), Orchidaceae (1270 taxa) and Asteraceae (1171 taxa) and Cyperaceae (609 taxa) (Table 3.6). The first ten dominant families of dicots comprise 36% of the total dicotyledon taxa and 37% of total dicotyledon genera recorded from India, whereas the first ten dominant families of monocotyledon represented 82% of the total monocotyledonous taxa and 88% of the total monocotyledon genera.

The ten most dominating of dicot and monocot genera are given in Table 3.7.

Out of the estimated 21,558 taxa of seed plants, about 18% species of trees are considered highly valued timber species and belong to the families like Meliaceae, Verbenaceae, Dipterocarpaceae, Fabaceae, Lauraceae, Euphorbiaceae, Annonaceae,

Table 3.5 Current estimation of angiosperm diversity of India

Category	Dicotyledons		Monocotyledon		Total
	Total	%	Total	%	
Family	222	83	46	17	268
Genera	2143	78	601	22	2744
Species	12,449	75	4190	25	16,639
Subspecies	274	80	63	20	337
Varieties	1237	81	281	19	1518
Forma	47	90	5	10	52
Total	16,372	76	5186	24	21,558
Cultivated	1189	85	215	15	1404
Total taxa	17,561	76	5401	24	22,962
Doubtful taxa	203	61	92	39	295

Table 3.6 Ten dominating families among flora of India

Dicotyledons			Monocotyledon		
Family	Taxa	Genera	Family	Taxa	Genera
Leguminosae	1292	176	Poaceae	1480	247
Asteraceae	1171	193	Orchidaceae	1270	155
Rubiaceae	635	101	Cyperaceae	609	32
Rosaceae	516	38	Zingiberaceae	232	21
Acanthaceae	514	43	Araceae	199	25
Euphorbiaceae	468	70	Eriocaulaceae	118	1
Labiatae	436	67	Arecaceae	110	20
Scrophulariaceae	374	62	Asparagaceae	108	16
Asclepiadaceae	317	47	Commelinaceae	96	12
Balsaminaceae	300	2	Dioscoreaceae	61	2
Total	6023	799	Total	4283	531

Table 3.7 Ten most dominating genera in flora of India

Dicotyledons		Monocotyledons	
Name of genera	Taxa	Name of genera	Taxa
Impatiens	299	*Carex*	208
Strobilanthes	156	*Bulbophyllum*	139
Primula	143	*Fimbristylis*	128
Crotalaria	127	*Eriocaulon*	118
Rhododendron	125	*Dendrobium*	116
Ficus	107	*Cyperus*	92
Saxifraga	104	*Poa*	67
Pedicularis	100	*Sorghum*	65
Potentilla	97	*Habenaria*	64
Syzygium	97	*Eria*	64
	1355	Total	1061

Moraceae, Mimosaceae, etc. The insectivorous plant families are represented by Droseraceae (3 species), Nepenthaceae (1 species) and Lentibulariaceae (36 species). The parasitic plant species are represented by Loranthaceae (46 species), Santalaceae (10 species), Balanophoraceae (6 species), Rafflesiaceae (1 species), Cuscutaceae (12 species) and Orobanchaceae (54 species).

3.10 Species Diversity

The quantitative assessment of species diversity is prerequisite for the precise evaluation of forest ecosystems, monitoring sustainability of its natural resources and long-term ecological research and conservation. Though these assessments are site specific, they provide a reliable data on various ecological attributes such as composition, abundance, distribution and dominance which ultimately help in understanding processes and dynamics of the entire landscapes. In a forest ecosystem, trees, shrubs, climbers and herbs are fundamental component that influences the resources and habitats for almost all other forest organisms. Very few data are available in this regard for the entire country. However, recent studies on rapid assessment of plant diversity of India conducted by Forest Survey India (FSI 2019) revealed very interesting result as given below.

Maximum tree diversity was found in tropical wet evergreen ($H' = 2.8$), tropical semi-evergreen forests ($H' = 2.9$) and tropical dry deciduous forests ($H'\supseteq = 2.8$), while the lower tree diversity is found in subtropical dry evergreen forests found in Jammu and Kashmir, Punjab, Haryana and Rajasthan ($H' = 1.2$). The tree diversity in Himalayan temperate forests ranges between ($H' = 1.8$ and 2.2).

Maximum shrub diversity is found in tropical wet evergreen forests ($H' = 3.3$) followed by tropical dry evergreen forests ($H' = 2.8$) and subtropical broadleaved forests of eastern Himalaya ($H' = 3.1$). Low shrub diversity is found in moist alpine scrubs forests ($H' = 1.2$) of Sikkim and Arunachal Pradesh.

Herb diversity is found maximum in tropical wet evergreen forests ($H' = 2.6$) followed by Himalayan moist temperate forests ($H' = 2.55$) and Himalayan dry temperate forests ($H' = 1.9$) of eastern Himalaya and north-east India (Arunachal Pradesh and Assam). Littoral and swamp forests of coastal ecosystems recorded the lowest herb diversity ($H' = 1.7$).

3.11 Threats to Diversity: Reason to Worry and Different Impacts

There are many factors which amplify the loss of biodiversity and thereby adversely affect its conservation and sustainable use. Conventionally, loss or fragmentation of habitat, over-exploitation of natural resources, natural calamities and desertification are the major drivers of biodiversity loss. More recently climate change and invasive alien species have been widely recognized as a serious threat to biodiversity.

Deforestation is a direct cause of loss or fragmentation of habitat. The main reasons can be attributed to shifting cultivation, rotational felling, other biotic pressures, diversion of forest lands for developmental activities, etc. Though the current estimate of gross deforestation in India is quite low (−0.43%) for 2009–2019 compared to the global average of −0.6%, but due to other human practices, the natural ecosystems on which survival of many species depend are under continuous pressure and remain vulnerable. In addition, overharvesting of natural resources contributes greatly to the loss of biodiversity. After habitat destruction, alien plants are the second biggest threat to biodiversity which not only affect the species composition and spatial distribution of the native flora but also impact on the resources, structures and functions of natural ecosystems. Recent studies revealed that *Ageratina adenophora* (IVI-62.76), *Hypoestes phyllostachya* (IVI-29.06) and

Ageratina riparia (IVI-50.91) are the most noxious species occurring between 1400 and 2250 m of elevation Himalaya; *Chromolaena odorata* (IVI-45.83), *Mikania micrantha* (IVI-59.64) and *Imperata cylindrica* (IVI-24.83) are observed only up to 1550 m of elevation; and 50–64% density of native flora were lost due to invasion of *Ageratum conyzoides* in Siwalik lowland forests of western Himalaya (Batish et al. 2009).

Climate-induced threats to plant diversity have a direct or indirect impact on the quality of the natural ecosystems, viz. change in phenology of plants, abundance and range of distribution, changes in community structure, shifting in habitat, changes in species richness, etc. (Dash 2018). The different impacts on biodiversity can be envisaged by many recent evidences. The early flowering of rhododendrons in eastern Himalaya, early flowering of very rare orchid species *Pleione scopulorum* in Vadse hills of Arunachal Pradesh, early flowering of apple trees in Bomdila and Mechuka regions of Arunachal Pradesh and spreading of flower blast disease in citrus plants in Himalaya may be attributed to shifting of phenology in high altitudes of Himalaya (Dash 2011). Patterns of plant species richness and life-forms along the altitudinal gradient in the Great Himalayan National Park (GHNP) reveal that there is a significant difference in the species composition in terms of percentages of trees, shrubs and climbers and the total life-forms in the middle altitudinal zone (1500–3000 m) and upper altitudinal (3000–4500 m) zone (Dash et al. 2021).

The species richness is greatly influenced by the local factor such as temperature, rainfall, humidity, etc. The species with smaller or more specialized populations with narrow distributed ranges are more likely to be adversely affected. For example, saprophytic orchids or other parasite plants such as *Galiola* sp., *Sapria himalayana, Balanophora dioca* and *Rhopalocnemis phalloides* depend upon the mycorrhizal fungus in their roots and organic matter for supply of nourishment. A slightest change in the microclimatic conditions would result in an unsuccessful establishment of new habitat. Similarly, species like *Amentotaxus assamica*, *Plectocomia himalayana, Tricarpelema glanduliferum, Zalacca secunda, Gleditsia assamica*, *Gymnocladus assamicus, Coptis teeta*, *Paphiopedilum fairrieanum* and many *Rhododendron* spp., with narrow habitat ranges (Dash and Mao 2011), would be affected most, as these plants need a particular bio-climatic characteristic to survive. Habitat loss along with the increase in temperature threatens the lowland species. For example, *Larsenianthus arunachalensis* and *Larsenianthus assamensis*, two beautiful endemic Zingiber plants, are found only in two localities; *Pleione scopulorum* is reported from one isolated patch sub-alpine slope in Vadse hills; many members of *Crawfurdia, Codonopsis, Ranunculus* and *Potentilla* which are observed in scattered populations in eastern Himalaya are vulnerable; and so on.

3.12 Conserving Biodiversity

Historically, fragmentation and change in habitat use, over-exploitation and technological change to meet the development needs have been the major drivers of changes in biodiversity status. In order to meet the challenges, the Government of

India from time to time formulated comprehensive policy and legislative and administrative measures for biodiversity conservation. The Government of India with the respective state governments had identified biodiversity-rich areas in different phytogeographic zones all across the country and set up in situ conservation sites. Presently, India has a network of 981 Protected Areas including 104 National Parks, 566 Wildlife Sanctuaries, 97 Conservation Reserves and 214 Community Reserves covering a total of 171,921 km^2 of geographical area of the country which is approximately 5.03% (National Wildlife database cell, accessed on 15 March 2021).

In addition, the National Environment Policy (2006) identifies the need for enhancement of ex situ conservation of genetic resources in designated gene banks across the country. The policy further emphasizes that the genetic material of threatened species of flora and fauna must be conserved on priority. It, therefore, becomes essential to provide alternate protection/shelter to such species. The Union Ministry of Environment and Forest, Government of India, initiated Scheme on Assistance to Botanic Gardens in 1991–1992 to promote ex situ conservation and propagation of indigenous threatened and endemic plants through the improvement of infrastructural facilities in Botanic Gardens (BGs), Botanic Sections in Popular Gardens and Centres of ex situ Conservation. It envisaged having a network of BGs/Botanic Sections in popular horticulture or thematic gardens all over the country by the end of 12th Five-Year Plan. The primary activities under the ABG schemes include ex situ conservation and multiplication of threatened and endemic plants; establishment of seed banks, arboreta and propagation facilities; and reintroduction of such plants in natural habitat; awareness on plant diversity, threatened and endemic species of the country in general and such species of the state/region in particular.

Since the initiation of the Scheme in 1992, it has till date established 345 Botanic Gardens, 19 Lead Botanic Gardens and 172 Botanic Gardens established by State Government/Horticulture department/Forest department in different phytogeographic zone all across the country. The number of living plant accessions recorded in these Botanic Gardens in India is about 2 lakhs with an approximate 8000–12,000 number of taxa in these collections.

India is a signatory to CBD; hence it has obligation to conserve our rich biodiversity. Implementation of conservation measures is often a challenge to any country; however effective and sustained measures are being taken by the Government of India through national missions, and the National Action Plan on Climate Change (NAPCC) for adaptation to and mitigation of adverse climate change effects. Public awareness. Capacity-building measures are being taken up on a regular basis to motivate and empower people to take conservation actions and adopt conservation-friendly lifestyles. Effective enforcement of the FC Act, Notifications under the EP Act for regulation of activities in coastal zone areas, encouragement of organic agriculture and soil health-based application of inputs in agriculture and diversion of demands from forests and natural habitats to alternative sources have made a substantial positive difference. However, the challenges continue and need constant review and realignment of strategies to meet the emerging requirements.

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Chapter 4
Biodiversity Status, Issues, and Challenges: Trees and Shrubs

Mustaqeem Ahmad, Daizy R. Batish, and Harminder Pal Singh

4.1 Introduction

India encompasses approximately 329 million hectares of land with seashore stretching up to 7500 km. Diversity of ecosystems including Western Ghats, Eastern Ghats, trans-Himalayan region, coastal region, cold and hot deserts, mangroves of Sundarbans and tropical wet evergreen forests of north-east India are found here (Fig. 4.1). India is home to ample biodiversity and reportedly has 47,513 plant species (Kamble and Yele 2020) and ~91,000 animal species (https://www.iucn.org/asia/countries/india). Floral and faunal diversity in India is mainly localized in the four biodiversity hotspots, namely, the Himalayas, the Western Ghats, Indo-Burma regions and Sundaland. Mangrove forests cover about 6749 km^2 in India (the fourth largest mangrove region in the world) and are unique in variability and diversity (Mandal and Naskar 2008). Coral reefs—the distinctive and fragile marine communities—are found in the Gulf of Kutch, Gulf of Mannar, Andaman and Nicobar Islands and Lakshadweep islands (Sahu et al. 2015). The desert ecosystems (hot and cold) cover almost 2% of the total landmass and have vegetation highly adapted to survive under adverse ecological conditions. Ladakh and Lahaul & Spiti regions of India constitute cold deserts of India, covering an area of about 109,990 km^2 (Arisdason and Lakshminarasimhan n.d.). On the contrary, the hot desert in the

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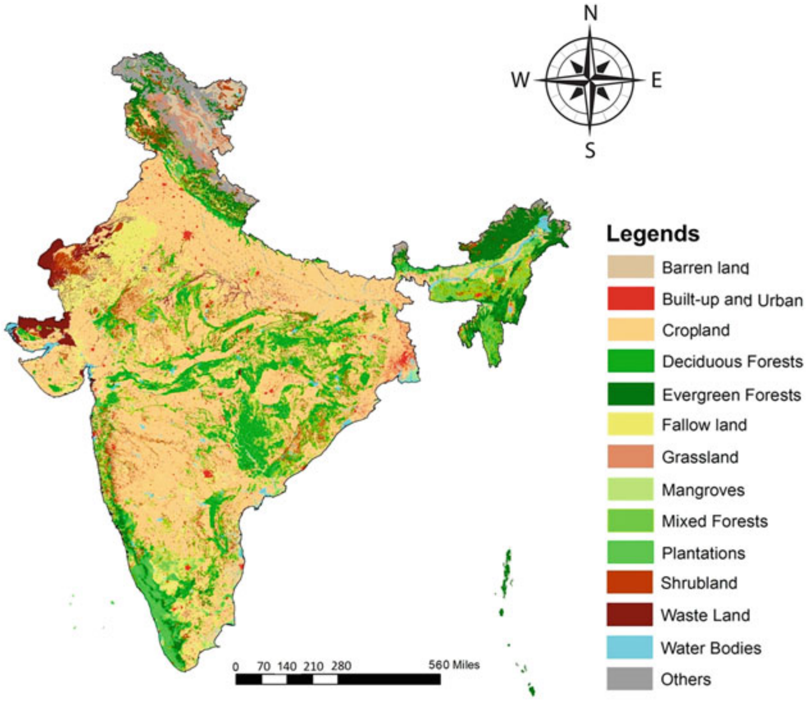

Fig. 4.1 Forest types and land cover of India (Source: Roy et al. 2016)

western part of Indian subcontinent has a dominantly sandy landscape with a different composition of species.

India has approximately 21.71% (713,789 km^2) of its total geographical area under forest cover, whereas the tree cover is around 2.91% of the world's total geographical area (FSI 2021). So far, 47,513 plant species have been recorded in the country, which constitutes 11.4% of the world flora; Of these, 28% of plant species are endemic (Kamble and Yele 2020). An overview of the number of plant species documented in India vis-à-vis in the world is given in Fig. 4.2.

4.2 Issues of Biodiversity in India

Biodiversity provides resources for sectors like pharmaceuticals, Ayurveda, agriculture, mining, etc. (Oldham et al. 2013). The loss of biodiversity and the extinction of species in India are occurring at an alarming rate. This loss is accompanied by the declining knowledge of biological diversity, which particularly affects the intricate relationship of humans with the natural ecosystem. Subtropical and tropical regions of the country are rich in biodiversity, but the presence of a well-rounded ecological

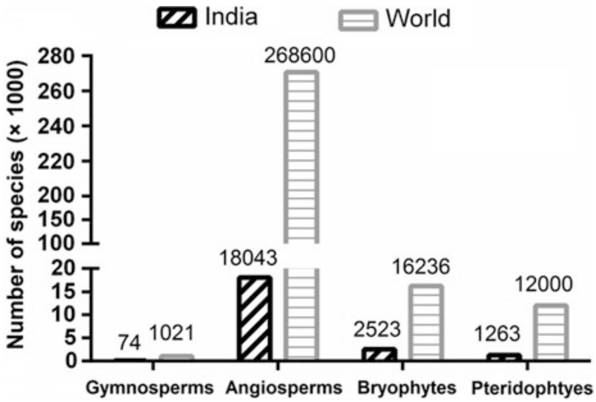

Fig. 4.2 Number of plant species and their status in India and the world (Chapman 2009; Singh and Dash 2014)

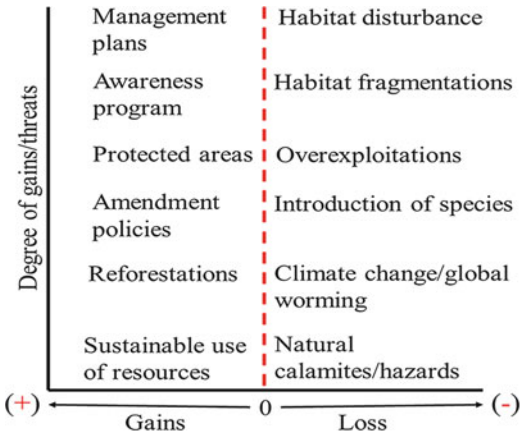

Fig. 4.3 Factors influencing biodiversity loss and gain

database is lacking. It is approximated that 27% of the Indian population directly depends upon the forests and their products for livelihood (Pandey et al. 2016). As per Lavanya et al. (2021), out of the 216.42 million tons of fuel wood required, 58.75 million tons is procured from the forest alone which puts an enormous pressure on the forests. Besides fuel wood, the low productivity of forests can also be attributed to various other factors such as grazing, over-exploitation, fire, non-recycling of biomass in forest soil, etc. Consequently, the biodiversity of India is under considerable threat due to various reasons, both natural and anthropogenic. Various natural reasons (like natural calamities, competition between species and biological imparity of a species) and human-made threats (clearance of forests for agriculture, mining, urban sprawl, population explosion, industrialization, climate change, global warming, over-grazing, over-exploitation of components of floristic diversity and introduction of alien species) have severely threatened the biodiversity. The most prominent factors influencing biodiversity loss and gain are represented in Fig. 4.3.

4.3 Threatened Species of India

According to the International Union for Conservation of Nature (IUCN), more than 58,343 plant species have been assessed as threatened worldwide (IUCN 2022). It is estimated that the number of Indian plants in the IUCN red list is steadily increasing which is a cause of concern for conservationists. In 2018, the red list featured 4537 endangered species globally, while in 2021, this number went up to 9400 (IUCN 2022). The total endemic and threatened plant species of India including gymnosperms, angiosperms, bryophytes and pteridophytes are presented in Fig. 4.4. The endemic flowering plant (angiosperms) of India are distributed amongst 141 genera belonging to 47 families (MoEF 2014).

The Botanical Survey of India (BSI) has also documented many locally/regional threatened species. Some threatened plant species with their ecological status are given in Table 4.1 (IUCN 2022).

4.4 Conservation Strategies

Over the past few decades, conservation and management of biodiversity have been enhanced and strengthened through various legal frameworks and policies for the management of biodiversity at regional and national levels. However, the most challenging task for the biodiversity conservation is the documentation of all the species. Nearly 30% of the geographical region of our country, including the Great Himalaya, the Western Ghats and the Andaman and Nicobar Islands, remain unexplored and non-inventorized (Arisdason and Lakshminarasimhan n.d.). Nevertheless, various conservation strategies have been discussed as under.

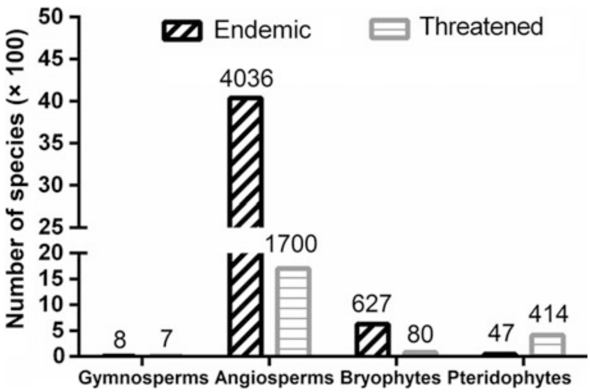

Fig. 4.4 Number of endemic and threatened plant species in India (Chapman 2009; Singh and Dash 2014)

Table 4.1 Some threatened species of India (Based on IUCN 2022; Gowthami et al. 2021)

S.No.	Species	Ecological status
1	*Actinodaphne lawsonii* Gamble	Vulnerable
2	*Albizia thompsonii* Brandis	Near threatened
3	*Amentotaxus assamica* D.K.Ferguson	Endangered
4	*Aquilaria malaccensis* Lam.	Critically endangered
5	*Cayratia pedata* var. *glabra* Gamble	Critically endangered
6	*Cinnamomum wightii* Meisn	Endangered
7	*Commiphora stocksiana* (Engl.) Engl	Endangered
8	*Commiphora wightii* (Arn.) Bhandari	Critically endangered
9	*Cupressus cashmeriana* Royle ex Carrière	Near threatened
10	*Cycas beddomei* Dyer	Endangered
11	*Decalepis hamiltonii* Wight & Arn.	Endangered
12	*Diospyros paniculata* Dalzell	Vulnerable
13	*Dipterocarpus tuberculatus* Roxb.	Near threatened
14	*Dysoxylum malabaricum* Bedd. ex C.DC.	Endangered
15	*Ephedra gerardiana* Wall. ex Stapf	Vulnerable
16	*Garcinia indica* (Thouars) Choisy	Vulnerable
17	*Ginkgo biloba* L.	Endangered
18	*Gymnema khandalense* Santapau	Endangered
19	*Gymnocladus assamicus* P.C.Kanjilal	Critically endangered
20	*Hopea odorata* Roxb.	Vulnerable
21	*Humboldtia vahliana* Wight	Endangered
22	*Hydnocarpus pentandrus* (Buch.-Ham.)	Vulnerable
23	*Ilex khasiana* Purkay.	Critically endangered
24	*Illicium griffithii* Hook.f. & Thomson	Endangered
25	*Jatropha nana* Dalzell & A.Gibson	Vulnerable
26	*Kingiodendron pinnatum* (DC.) Harms	Endangered
27	*Magnolia nilagirica* (Zenker) Figlar	Vulnerable
28	*Nepenthes khasiana* Hook.f.	Endangered
29	*Piper barberi* Gamble	Endangered
30	*Pterocarpus indicus* Willd.	Endangered
31	*Pterocarpus marsupium* Roxb.	Near threatened
32	*Pterospermum reticulatum* Wight & Arn.	Vulnerable
33	*Rhododendron dalhousiae* Hook.f.	Vulnerable
34	*Santalum album* L.	Vulnerable
35	*Syzygium travancoricum* Gamble	Critically endangered
36	*Terminalia pallida* Brandis	Vulnerable

4.4.1 Role of in Situ Conservation

India has established a total of 987 Protected Areas (PAs) which include 104 National Parks, 566 Wildlife Sanctuaries, 214 community reserves and

97 conservation reserves, besides 49 Ramsar sites and 18 Biosphere Reserves (ENVIS 2022). In addition, several tree/shrub improvement and development programmes have been undertaken with the motive of increasing the number and volume of timber and non-timber species.

4.4.2 Role of Government Regulations

The first effort to manage forests was undertaken by the state governments as per the guidelines of the National Forest Policy (NFP), 1988. Later, National Forestry Action Programme (NFAP) was initiated with the goal of inscribing the matter and issues of the forestry sector with the NFP, 1988. These programmes included in situ and ex situ conservation of genetic resources of forests. The National Forestry Research Plan (NFRP) helps in avoiding the duplication and replication of research. The National Wildlife Action Plan (NWAP) deals with the protection of fauna and flora in the Protected Area Network. National Biodiversity Action Plan (NBAP), 2008, National Action Plan on Climate Change (NAPCC), 2008 and Mangroves for the Future-National Strategy and Action Plan (MFF-NSAP), 2011 deal with the use and conservation of natural resources at national level. Nevertheless, the legislations associated with biodiversity conservation, sustainable management and access and sharing are made in Biological Diversity Act, 2002. The collection and transportation of forest resources from wild are monitored by the Indian Forest Act, 1927, Wildlife (Protection) Act, 1972 and various State Forest acts. The export and trade of biological resources are ruled by CITES (Convention on International Trade in Endangered Species of fauna and flora), including the conservation of endangered natural resources.

4.4.3 Role of International Collaborations and Agreements

The Ministry of Environment, Forest and Climate Change (MoEF&CC) is the nodal agency responsible for the management of environment and forests in India. It has an accord with United Nations Development Programme (UNDP), United Nations Industrial Development Organization (UNIDO), World Bank (WB), United Nations Conference on Sustainable Development (UNCSD), Global Environment Facility (GEF), United Nations Environment Programme (UNEP) and regional frameworks like South Asian Association for Regional Cooperation (SAARC), Economic and Social Commission for the Asia and the Pacific (ESCAP), South Asian Cooperative Environmental Programme (SACEP), Asian Development Bank (ADB), European Union (EU) and International Treaty on Plant Genetic Resources (ITPGR). India has participated and attended all the major international activities associated with biodiversity conservation over the past few years and has signed most of the biodiversity- and environment-related global conventions and treaties.

UNDP is supporting several initiatives to conserve rich and diverse ecosystems of India and demonstrate strategies to reduce poverty across the country. MoEF&CC focuses on the socio-economic importance of biodiversity and ecosystem services to support global conservation objectives while recognizing the inner value of biodiversity. It also opens the opportunities for making natural resources a fundamental part of economies while at the same time ensuring the equitable sharing of benefits from biodiversity resources.

4.5 Shrub and Tree Diversity in India

Trees and shrubs are important components of vegetation, and their composition influences the structure, function, climate and geomorphology of an area. Their status and conservations both are of utmost importance. Their speedy documentation helps in devising suitable management strategies and policies for conservation and sustainable use of forests.

4.5.1 Diversity of Shrub Species in India

The richness and abundance of shrubs declined due to the various natural as well as anthropogenic processes. In Himalayas, Central India, and the Western Ghats, shrubs are being used to feed the livestock. The shrubs serve as subsidiary fodder at the time, when green fodder is lacking and are also good source of fuel wood. Samant et al. (2000) reported 31 fuelwood species in Kumaun Himalaya which include shrubs like *Woodfordia fruticosa* and *Berberis aristata*. Dominant shrub species such as *Caesalpinia pulcherrima*, *Mussaenda glabrata*, *Bougainvillea*, *Lantana*, *Lawsonia*, *Ixora, Hibiscus, Gardenia*, *Magnolia champaca*, etc. found in central India are used for fuel wood, timber, fodder and ornamental purposes. Kala (2010) reported seven common shrubs (*viz. Rhus parviflora, Rubus ellipticus, Berberis asiatica, Carissa opaca, Ficus palmata, Euphorbia royleana* and *Vitex negundo*) which are used for the purpose of indigenous agroforestry system in Uttarakhand. Some dominant shrubs found in India are listed in Table 4.2.

4.6 Diversity of Tree Species in India

Tree species play a key role in deciding the structure, composition, and functional elements of a forest ecosystem. Tropical countries have recorded the world's highest tree species richness and endemism in the mountainous regions which may be attributed to variations in climatic and edaphic conditions.

Table 4.2 List of some dominant shrubs found in India

S. No.	Location	Name of species found	References
1	Northern India	*Abelia triflora* R.Br. ex Wall., *Caesalpinia pulcherrima* L., *Cassia glauca* Lam., *Calliandra tweedii* Benth., *Caragana brevispina* Benth., *Colutea nepalensis* Sims, *Cotoneaster bacillaris* Wall. ex Lindl., *Cotoneaster microphyllus* Wall. ex Lindl., *Fraxinus xanthoxyloides* (G.Don) Wall. ex A.DC., *Hippophae rhamnoides* L., *Juniperus communis* L., *Juniperus indica* Bertol., *Lonicera alpigena* L., *Lonicera orientalis* var. *kachkarovii* Batalin, *Lonicera myrtillus* Hook. f. & Thomson, *Lonicera quinquelocularis* Hard., *Myricaria germanica* (L.) Desv., *Ribes orientale* Desf., *Salix denticulata* subsp. hazarica (R. Parker) Ali, Sw., *Ribes orientale* Desf., *Rosa webbiana* Wall. ex Royle, *Salix alba* L., *Sorbaria tomentosa* (Lindl.) Rehder	Verma and Kapoor (2011), Kaur et al. (2013)
2	Southern India	*Adhatoda vasica* Nees, *Calotropis gigantea* (L.) Dryand., *Carissa carandas* L., *Cassia alata* L., *Citrus medica* L., *Datura metel* L., *Ervatamia coronaria* (Jacq.) Stapf, *Hibiscus rosa-sinensis* L., *Ixora coccinea* L., *Jatropha curcas* L., *Lantana camara* L., *Nerium indicum* Mill., *Punica granatum* L., *Toddalia asiatica* (L.) Lam., *Vitex negundo* L.	Naik et al. (2008)
3	Western Ghats	*Agrostistachys indica* Dalzell, *Barleria involucrata* Nees, *Croton zeylanicus* Müll.Arg., *Diotacanthus grandis* (Bedd.) Benth., *Erythroxylum lanceolatum* (Wight) Walp., *Euonymus crenulatus* Wall. ex Wight & Arn., *Mallotus beddomei* Hook.f., *Microtropis wallichiana* Wight ex Thwaites, *Nilgirianthus barbatus* (Nees) Bremek., *Nilgirianthus foliosus* (Wight) Bremek., *Phyllanthus fimbriatus* (Wight) Müll.Arg., *Sarcandra chloranthoides* Gardner	Krishnan and Davidar (1996)
4	Eastern Ghats	*Abutilon neilgherrense* Munro, *Cycas beddomei* Dyer, *Carissa inermis* Vahl, *Cassia montana* Naves & Villar, *Carissa paucinervia* A.DC., *Cycas circinalis* L., *Decaschistia cuddapahensis* T.K.Paul & M.P.Nayar, *Decaschistia rufa* Craib, *Flacourtia indica* (Burm.f.) Merr., *Grewia heterotricha* Mast., *Euonymus dichotomus* B.Heyne ex Wall., *Dalechampia velutina* Wight, *Jatropha tanjorensis* J.L.Ellis & Saroja, *Justicia gingiana* Sebastine & Ramam., *Lasianthus truncatus* Bedd., *Maytenus bailadillana* (V.Naray. & Mooney) D.C.S.Raju & Babu, *Memecylon jadhavii* K.N.Reddy, C.S.Reddy & V.S.Raju, *Memecylon lushingtonii* Gamble, *Mimosa barberi* Gamble, *Memecylon madgolense* Gamble, *Miliusa montana* Gardner ex Hook.f. & Thomson, *Nilgirianthus heyneanus* (Nees)	Reddy et al. (2002)

(continued)

Table 4.2 (continued)

S. No.	Location	Name of species found	References
		Bremek., *Pavetta breviflora* DC., *Pavetta blanda* Bremek., *Pavetta brunonis* Wall. ex G.Don, *Pavetta madrassica* Bremek., *Phlebophyllum spicatum* (Roth) Bremek., *Phlebophyllum versicolor* (Wight) Bremek., *Sida beddomei* K.C.Jacob, *Sophora glauca* DC., *Sophora interrupta* Bedd., *Tabernaemontana gamblei* Subr. & A.N.Henry, *Vernonia shevaroyensis* Gamble, *Wendlandia tinctoria* (Roxb.) DC.	

4.6.1 Dominant Tree Vegetation in Different Forest Types of India

The wider panorama of Indian forests stretches from tropical wet evergreen forests in the Andaman and Nicobar Islands, the Western Ghats, and the northeastern states to dry alpine scrub high in the Himalaya in the north. The country has thorn forests, semi-evergreen forests, deciduous forests and subtropical pine forests in the lower montane zone and temperate montane forests in the higher zones. On the other extreme, tropical dry deciduous and thorn forests predominate in the semi-arid areas of Rajasthan and Gujarat (FSI 2021). As per FSI (2021), forest cover of India constitutes 21.71% which includes 3.04% very dense forest, 9.33% moderately dense forest and 9.34% open forest. The total forest cover varies among different states and union territories of India (Fig. 4.5 a, b).

The highest forest cover is found in Mizoram followed by Arunachal Pradesh, whereas minimum forest cover was recorded in the agricultural states of Punjab and Haryana (Fig. 4.5a). Among the union territories, maximum forest cover is found in Lakshadweep, whereas minimum is found in Ladakh (Fig. 4.5b).

Several types of forests have been reported in India. Champion and Seth (1968) classified Indian forests into 16 types based on their nature and composition and type of climate. The dominant species and percent cover of these 16 types of forests are given in Table 4.3.

4.7 Dominant Tree Vegetation of the Indian Himalaya

The Indian Himalayan mountains are the youngest, and among the most unstable mountains in the world, and cover ~12.84% of the world's geographical area (Negi 2009). The Indian Himalaya is divided into western, central, and eastern Himalaya and consists of ~8000 angiosperms, 44 gymnosperms, 1737 bryophytes and 600 pteridophytes (Samant et al. 2007). Singh and Singh (1987) classified the Indian Himalaya into 11 forest types based on rainfall and temperature pattern, and these

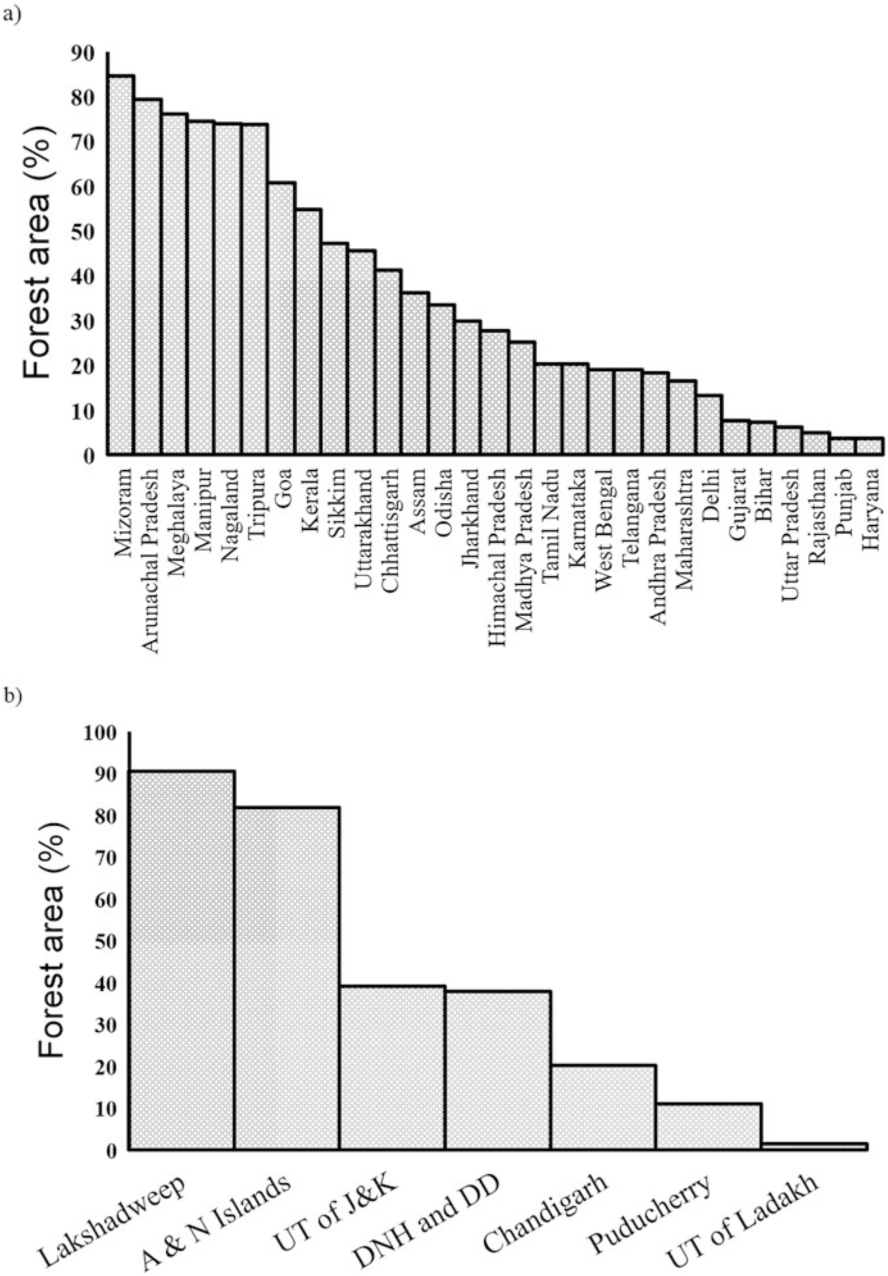

Fig. 4.5 (**a**) Forest cover among different states of India (Source: FSI 2021). (**b**) Forest cover in Union territories (UTs) of India (Source: FSI 2021). A&N: Andaman and Nicobar Islands, DNH: Dadra and Nagar Haveli, DD: Daman and Diu

Table 4.3 Different types of forest, their percent area and major vegetation

S. No.	Forest type	Percent area (%)	Dominant tree vegetation
1	Tropical wet evergreen forests	2.61	*Olea dioica* Roxb., *Schleichera trijuga* Willd., *Knema cinerea* Warb., *Hopea* species, *Syzygium cumini* (L.) Skeels, *Diospyros assimilis* Bedd., *Terminalia paniculata* Roth, *Holigarna arnottiana* Hook.f., *Linociera malabarica* Wall. ex G.Don, *Vateria indica* L.
2	Tropical semi-evergreen forests	9.27	*Terminalia paniculata* Roth, Castanopsis species, *Terminalia crenulata* Roth, *Tectona grandis* L.f., *Schima wallichii* Choisy, *Olea dioica* Roxb., *Macaranga* species, *Xylia xylocarpa* (Roxb.)., *Syzygium cumini* (L.) Skeels, *Albizia* species
3	Tropical moist deciduous forests	17.65	*Shorea robusta* Gaertn., *Tectona grandis* L.f., *Terminalia crenulata* Roth, *Anogeissus latifolia* (Roxb. ex DC.) Wall. ex Guillem. & Perr., *Cleistanthus collinus* (Roxb.) Benth. ex Hook.f., *Lannea coromandelica* (Houtt.) Merr., *Terminalia paniculata* Roth., *Lagerstroemia parviflora* Roxb., *Mallotus philippensis* var. *pallidus*, *Xylia xylocarpa* (Roxb.) Taub.
4	Littoral and swamp forests	0.73	*Avicennia marina* (Forssk.) Vierh., *Excoecaria agallocha* L., *Avicennia officinalis* L., *Aegiceras corniculatum* (L.) Blanco, *Dalbergia sissoo* DC., *Trewia nudiflora* var. *dentata* Susila & N.P.Balakr., *Tectona grandis* L.f., *Schleichera trijuga* Willd., *Bridelia retusa* (L.) A.Juss., *Shorea robusta* Gaertn.
5	Tropical dry deciduous forests	40.86	*Tectona grandis* L.f., *Shorea robusta* Gaertn., *Anogeissus latifolia* (Roxb. ex DC.) Wall. ex Guillem. & Perr., *Terminalia crenulata* Roth, *Lannea coromandelica* (Houtt.) Merr., *Lagerstroemia parviflora* Roxb., *Chloroxylon swietenia* DC., *Butea monosperma* (Lam.) Taub., *Cleistanthus collinus* (Roxb.) Benth. ex Hook.f., *Diospyros melanoxylon* Roxb.
6	Tropical thorn forests	2.72	*Anogeissus latifolia* (Roxb. ex DC.) Wall. ex Guillem. & Perr., *Albizia amara* (Roxb.) B.Boivin, *Chloroxylon swietenia* DC., *Hardwickia binata* Roxb., *Canthium dicoccum* (Gaertn.) Merr., *Wrightia tinctoria* R.Br., *Lannea coromandelica* (Houtt.) Merr., *Pterocarpus santalinus* L.f., *Eucalyptus* species, *Grewia* species
7	Tropical dry evergreen forests	0.12	*Albizia amara* (Roxb.) B.Boivin, *Syzygium montanum* Thwaites & Hook.f., *Premna tomentosa* Willd., *Canthium dicoccum* (Gaertn.) Merr., *Acacia lenticularis* Benth., *Chloroxylon swietenia* DC., *Albizia* species, *Memecylon angustifolium* Wight
8	Subtropical broadleaved hill forests	4.26	*Schima wallichii* Choisy, *Castanopsis* species, *Pinus kesiya* Royle ex Gordon, *Quercus* species, *Alnus nepalensis* D.Don, *Macaranga* species, *Albizia* species,

(continued)

Table 4.3 (continued)

S. No.	Forest type	Percent area (%)	Dominant tree vegetation
			Callicarpa arborea Roxb., *Chukrasia velutina* M. Roem., *Acacia auriculiformis* Benth.
9	Subtropical pine forests	2.36	*Pinus roxburghii* Sarg., *Quercus leucotrichophora* A. Camus, *Rhododendron arboreum* Sm., *Lyonia ovalifolia* (Wall.) Drude, *Mallotus philippensis* (Lam.) Müll.Arg., *Schima wallichii* Choisy, *Shorea robusta* Gaertn., *Myrica sapida* Wall., *Acacia catechu* (L.f.) Willd., *Quercus semecarpifolia* Sm.
10	Subtropical dry evergreen forests	0.02	*Punica granatum, Nerium* species and *Olea* species
11	Montane wet temperate forests	2.66	*Alnus nepalensis* D.Don, *Castanopsis* species, *Quercus* species, *Symplocos laurina* (Retz.) Wall. ex G. Don, *Michelia* species, *Callicarpa arborea* Roxb., *Symplocos theaefolia* D. Don., *Abies pindrow* (Royle ex D.Don) Royle, *Schima wallichii* Choisy, *Canarium bengalense* Roxb.
12	Himalayan moist temperate forests	3.35	*Quercus leucotrichophora* A.Camus, *Pinus roxburghii* Sarg., *Rhododendron arboreum* Sm., *Lyonia ovalifolia* (Wall.) Drude, *Pinus excelsa* Lam., *Quercus semecarpifolia* Sm., *Cedrus deodara* (Roxb. ex D.Don) G.Don, *Quercus dilatata* A.Kern., *Abies pindrow* (Royle ex D.Don) Royle, *Abies smithiana* (Wall.) Lindl.
13	Himalayan dry temperate forests	0.73	*Quercus semecarpifolia* Sm., *Pinus excelsa* Lam., *Abies smithiana* (Wall.) Lindl., *Quercus dilatata* A.Kern., *Betula utilis*, *Taxus baccata* L., *Acer* species, *Prunus cornuta* (Wall. ex Royle) Steud.
14	Sub-alpine forests	1.96	*Abies densa* Griff., *Abies pindrow*, *Pinus excelsa* Lam., *Quercus semecarpifolia* Sm., *Quercus* species, *Rhododendron arboreum* Sm., *Acer* species, *Prunus cornuta* (Wall. ex Royle) Steud., *Alnus nepalensis* D.Don, *Abies smithiana* (Wall.) Lindl.
15	Moist alpine scrubs	0.13	*Pinus excelsa* Lam., *Quercus* species, *Rhododendron arboreum* Sm., *Alnus nepalensis* D.Don., *Phoebe* species, *Quercus semecarpifolia* Sm., *Rhododendron* species, *Abies densa* Griff., *Quercus griffithii* Hook.f. & Thomson ex Miq., *Abies pindrow* (Royle ex D.Don) Royle
16	Dry alpine scrubs	0.38	*Lonicera* species, *Juniperus flaccida*, *Juniperus indica*, *Salix* species

Note: Percent area of different forest types is as per FSI (2021)

are submontane broadleaf ombrophilous forest, submontane seasonal broadleaf forest, submontane broadleaf summer deciduous forest, low-montane needle-leaf forest with concentrated summer leaf drop, low-montane sclerophyllous evergreen broadleaf forest, low-montane sclerophyllous evergreen broadleaf forest, mid-montane broadleaf ombrophilous forest, low to mid-montane hemi-sclerophyllous broadleaf forest with concentrated summer leaf drop, mid-montane needle-leaf evergreen forest, mid-montane winter deciduous forest, high-montane mixed stunted forest and very high-montane scrub forest.

4.8 Dominant Tree Vegetation of Western Ghats

Utkarsh et al. (1998) reported evergreen forests, semi-closed evergreen forests, stunted evergreen forests, semi-evergreen forests, moist deciduous forests and dry deciduous forests to be the major types of forests in the Western Ghats. *Persea macrantha, Hopea parviflora, Cinnamomum* spp.*, Mangifera indica, Memecylon umbellatum, Olea dioica, Macaranga peltata, Mallotus philippensis, Terminalia bellirica* and *Careya arborea* are some of the most dominant species found in Western Ghats (Utkarsh et al. 1998).

4.9 Dominant Tree Vegetation of the Eastern Ghats

According to Gopalakrishna et al. (2015), *Anogeissus latifolia, Acacia chundra, Acacia caesia, Cedrela toona, Ixora arborea, Gymnosporia montana, Diospyros melanoxylon, Dalbergia paniculata, Ochna squarrosa, Fagraea ceilanica, Shorea roxburghii, Cassia alata, Pavetta indica, Stereospermum xylocarpum, Cassia fistula, Lagerstroemia parviflora* and *Grewia villosa* are the dominant tree species of Eastern Ghats.

4.10 Conclusion

Trees and shrubs, the important components of biodiversity, are declining fast owing to both natural and anthropogenic reasons. Being climax communities, they are long-lasting and hence continuous source of ecosystem services for the people. Despite multitude of efforts made by government in the form of policies, acts, awareness programmes, the establishment of protected areas, etc., not much significant change in the current status has been noticed. Efforts should be made to document the species in a centralized database to maintain uniformity and focus on their conservation, especially of threatened and endemic ones. Himalaya, a biodiversity hotspot with high degree of endemism, is a repository of plant diversity. Unfortunately, rate of degradation is also fast; as a result, several species now have been listed in various IUCN risk categories. Therefore, stringent legislation and rigorous policies are required to conserve the existing biodiversity. Collective efforts of government and people are required for the sustainable management of ecosystems in order to conserve the Indian tree and shrub diversity.

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Chapter 5
Underutilized Plants in India

Arnab Banerjee and Paramjit Singh

5.1 Introduction

Of the estimated 350,000 plant species known in the world, more than 30,000 are edible, and out of about 7000 plants used as human food, just 15 crop plants contribute to over 90% of global plant-derived energy intake and of these, only 3—wheat, rice and maize—account for sustaining 4 billion people (Antonelli et al. 2020). But millions around the world still suffer from hunger or obesity because they lack a balanced nutritious diet (FAO 1997, 2013; Antonelli et al. 2020).

If the twentieth century witnessed the systematic collection of genetic resources of staple crops (Pistorius 1997; Eyzaguirre et al. 1999), in the twenty-first century, the focus should be on rescuing and improving the use of those crops through research, technology, and marketing systems as well as conservation efforts. These underutilized plants (also known by other terms such as minor, neglected, underexploited, underdeveloped, new, novel, promising, alternative, local, traditional, niche crops) have caught the interest of decision-makers. Leading international research organisations such as the Consultative Group on International Agricultural Research (CGIAR) are also among those displaying a keen interest in strengthening research on such underutilized species (Swaminathan 1999).

Human life and civilizations have been influenced not only by cultivated taxa but also by their wild germplasm. The origin and evolution of agricultural crops from the wild progenitors aided by domestication have attracted the attention of evolutionary biologists, plant explorers, archaeo-botanists, geneticists, molecular biologists and

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plant breeders worldwide. But climate change and population growth impact all these developments and impact nutritional security (FAO 2013; Da Silva 2014).

Natural plant resources have been playing a pivotal role in providing almost every need for the survival of people, especially in poor and underdeveloped communities. These are the basic source of food, medicine and other everyday needs of people; thus they play a pivotal role in sustenance and poverty alleviation (Bates 1985; Kumar et al. 1994; Everest and Ozturk 2005; Joshi and Joshi 2006; Goel 2007). The active ingredients found in 20–25% of prescription drugs come from plants (Smith-Hall et al. 2012). An estimated 80% of vitamin A and more than a third of the vitamin C in the diet of tribal population are supplied by traditional plants (Duhan et al. 1992; Bhargava et al. 1996; Bhat and Karim 2009; Vadivel and Pugalenthi 2010; Jain and Tiwari 2012; Deb et al. 2013).

Malnutrition, poor health, hunger and starvation are still the world's greatest challenges. Currently, the Food and Agriculture Organization of the United Nations (FAO 2013; Da Silva 2014) estimates that around 800 million people still suffer from food and nutrition insecurity, particularly in underprivileged population groups. According to the World Food Program (www. wfp.org/hunger/stats), poor nutrition causes nearly half (45%) of deaths in children under 5, which accounts for about 3.1 million children every year. Worldwide, at least 120 million women in less developed countries are underweight (Blossner and de Onis 2005).

More than one billion people in our country are still dependent on nurturing and harnessing rich biodiversity for food and nutritional security. Different underutilized species are characterized based on their needs for development and use (Jaenicke and Höschle-Zeledon 2006). There exists a myriad of completely wild and semi-domesticated species (Heywood 1991, 1999; Sundriyal & Sundriyal 2003). Wild relatives of crops are particularly important in our response to climate change (Hunter and Heywood 2011).

India, the seventh largest in the world and second largest in Asia in terms of biogeographical area, is a mega-biodiversity country and is recognized as one of the global biodiversity hotspots (Myers et al. 2000). A great variety of climatic and altitudinal variations, coupled with varied ecological habitats, have contributed immensely to the rich floristic diversity of this country. Its physiographic diversity has produced all possible types and extremities of climatic conditions suitable for supporting varied types of ecosystems. It demonstrates both extremes, from almost rainless areas in western Rajasthan and Ladakh to the world's rainiest areas in northeast India; from tropical, hot and humid to coldest arctic climate; and from vast riverine plains and delta of the mighty Ganga and Brahmaputra to high mountains of the Himalayas. The altitude varies from sea level to the highest mountain ranges of the world. The habitat types vary from the humid tropical Western Ghats to the hot deserts of Rajasthan, from the cold deserts of Ladakh and the icy mountains of the Himalayas to the long, warm coastline stretch of Peninsular India (Singh 2020). The extreme diversity of the habitats has resulted in such luxuriance and variety of flora that all types of forests, ranging from scrub forests to tropical evergreen rain forests, coastal mangroves to temperate and alpine vegetation, occur in the country. A significant feature of the Indian flora is the confluence of species from the regions such as Malaya, Tibet, China, Japan and Europe and even from widely separated continents of America, Africa and Australia (Sharma 2000).

5.2 Underutilized Plants from Angiosperms

The Indian subcontinent is a reservoir of several plant species, with immense potential to be utilized for the benefit of human beings. India occupies a unique position among the major gene-rich countries of the world with a bounty of 49,003 species of plants forming the evident vegetal cover in India, out of which angiosperms comprise ca. 18,532 species, representing >10% of the world's known flowering plant species (Singh and Dash 2018). About 23% of these species are endemic occurring in 16 major vegetation types of the country (Singh et al. 2015). Several systematic efforts have been made to compile information on lesser-known food plants including wild resources used by farmers and tribal communities in different regions of the country. Ethnobotanical investigations have been made to record wild plant species used by native tribal and aboriginal people to meet their varied requirements (Jain and Sinha 1987; Maikhuri, 1991; MEF 1994).

Out of 416 recognized plant families, 257 families, with more than 4000 genera, are represented in the Indian flora, of which Poaceae is the largest family with more than 1200 species in about 260 genera. Some families which have a genus with large number of species are Balsaminaceae (*Impatiens* with 200 species), Primulaceae (*Primula* with 135 species), Fabaceae (*Crotalaria* with 104 species), Moraceae (*Ficus* with 100 species), Scrophulariaceae (*Pedicularis* with 98 species), Ericaceae (*Rhododendron* with species), Myrtaceae (*Syzygium* with 91 species), Saxifragaceae (*Saxifraga* with over 130 taxa) and Piperaceae (*Piper* with 88 species). Some families of flowering plants are represented in India by just one species each; these include Akaniaceae, Turneraceae, Illiciaceae, Ruppiaceae and Tetracentraceae (Singh 2020).

Impatiens, Carex, Dendrobium, Habenaria, Rhododendron, Taraxacum, Pedicularis, Astragalus, Saussurea, Citrus, Ficus and *Primula* are some of the species-rich genera; moreover bamboos and hedychiums also exhibit remarkable diversity in the country. About 15% species are trees, which include some of the highly valued timber species of the world, belonging to families Meliaceae, Verbenaceae, Dipterocarpaceae, Fabaceae, Lauraceae, Euphorbiaceae, Annonaceae, Moraceae, etc.

Some of the species of *Arenaria, Thylacospermum*, *Acantholimon*, *Saussurea*, etc., growing in cold deserts, are highly adaptive for survival in harsh conditions. There are several botanical curiosities, such as *Nepenthes khasiana* Hook.f., *Sapria himalayana* Griff., *Mitrastemon yamamotoi* Makino, *Balanophora dioica* R.Br. ex Royle, *Boschniakia himalaica* Hook.f. & Thomson, *Aeginetia indica* L. and species of *Utricularia, Drosera*, *Pinguicula, Galeola*, *Epipogium*, *Monotropa*, etc. The insectivorous plant families are represented by Lentibulariaceae (36 spp.), Droseraceae (3 spp.) and Nepenthaceae (1 sp.). The parasitic plant species are prominent in Orobanchaceae (54 spp.), Loranthaceae (46 spp.), Cuscutaceae (12 spp.), Santalaceae (10 spp.), Balanophoraceae (6 spp.) and Rafflesiaceae (1 sp.). Most of these unique assets of the Indian flora have not even been understood in terms of their reproductive behaviour, distribution pattern and ecological preferences, let alone their chemical profiling and potential uses.

Similarly, thousands of ethnobotanically significant species have been reported from India, and many of them can be directly used as a source of medicine or as genetic resources for the improvement of the medicinal properties of cultivated species (MEF 1994). Interestingly, the Indian subcontinent comprises all types of bioenergy plants including oil-producing plants such as *Pongamia pinnata* (L.) Pierre, *Jatropha curcas* L., *Ricinus communis* L., *Sapindus mukorossi* Gaertn. and *S. trifoliatus* L. and dedicated bioenergy plants such as eucalyptus, poplar, willow, birch, giant reed, reed canary grass, switchgrass, elephant grass and Johnson grass. Moreover, species of *Acacia*, *Prosopis*, *Populus*, *Salix*, *Betula*, *Pinus*, bamboo, *Bothriochloa*, *Cenchrus*, *Cynodon*, *Dichanthium* (grasses), *Desmodium* and *Mucuna* (forage legumes) are candidate species for soil carbon sequestration. Similarly, species like *Brassica juncea* L. Czern., *B. carinata* A.Braun and *Hordeum vulgare* L. are good accumulators of lead, whereas *Salix viminalis* L. can phytoremediate arsenic and cadmium, respectively. Furthermore, wild species such as *Bothriochloa intermedia* (R.Br.) A.Cam., *B. pertusa* (L.) A.Camus, *Chrysopogon aciculatus* (Retz.) Trin., *C. hamiltonii* (Hook. f.) Haines, *Eragrostis curvula* (Schrad.) Nees, *Populus ciliata* Wall. ex Royle and *Salix tetrasperma* Roxb. can prevent soil degradation and erosion, whereas the species like *Medicago lupulina* L., *M. monantha* (C.A. Mey.) Trautv. and *Alnus nepalensis* D.Don can be used for the restoration of degraded soils (Mohan & Janardhanan 1995; Thothathri 2000; Singh 2000; Pugalenthi et al. 2005).

5.3 The Wild Relatives of Crop Plants in India

Wild relatives of crop plants constitute a part of the crop gene pool, which possesses genes that have great utilization potential in crop improvement programmes (Singh 2017). Wild gene pools, especially those occurring in biotically disturbed habitats, are under threat of genetic erosion and require immediate conservation to make use of their wider adaptability, tolerance/resistance to disease and insect pests, yield, quality attributes and other biotic and abiotic traits. About 320 wild relatives of various crops are stored in the Indian gene centre (Arora 2000).

The majority of wild relatives of cultivated plants and related and endemic/rare/endangered species occur in the hotspots/micro-centres of India (Nayar 1996; Samant & Dhar 1997; Arora 2000; Singh et al. 2015). The wild plant taxon can have many indirect uses, i.e. can be utilized for crop improvement and also play an important role in maintaining a sustainable environment, and agroecosystems (Dempewolf et al. 2017). These wild taxa have multiple utilities such as edibles, fibres, oilseeds, spices, medicines and even non-timber forest products for local trading.

Wild crop relatives are generally utilized for producing complex hybrids and conferring disease and insect pest resistance in some of the staple crops like rice, wheat, peas, etc. For instance, wild rice *Oryza longistaminata* A.Chev. & Roehr. has been used for transferring the rice bacterial blight (*Xanthomonas* infection) disease-resistant gene Xa21 into *Oryza sativa* L. Similarly, in the USA, the corn blight disease in maize was overcome by the introduction of blight resistance genes from the wild Mexican maize plants. Similarly, cyst nematode-resistant gene from *Cicer reticulatum* Ladiz. and cold tolerance gene from *C. reticulatum* and *C. echinospermum* P.H.Davis have been utilized for breeding cold and nematode-tolerant *C. arietinum* L. Furthermore, several wild varieties having several abiotic stress tolerances have also been used for developing climate-smart crops. For example, the genes from wild species of rice such as *Oryza rufipogon* Griff. are capable of conferring tolerance to acidic sulphate and drought tolerance. Moreover, there are several examples of wild species that are used for increasing the yield traits (e.g. in sugarcane and tomato) and quality traits such as protein content, e.g. in durum wheat by crossing *Triticum durum* Desf. × *T. dicoccoides* (Körn. ex Asch. & Graebn.) Schweinf., grain weight, nutritive value, earliness and adaptation, colour, leaf texture, delayed ripening of fruits, etc. (Joshi & Paroda 1991).

The use of wild crop varieties for dietary supplementation has been reported from various parts of the country. More than 50 wild vegetables, 29 wild fruits, 8 nuts, 6 beverages and drinks, 4 grains, 3 oilseeds, etc. have been documented from the Bastar region of Chhattisgarh, India, alone (Singh 2013). Similarly, the occurrence of wild species such as *Amaranthus spinosus* L., *Smelowskia tibetica* (Thomson) Lipsky, *Allium carolinianum* DC., *Chenopodium foliosum* Asch., etc. has been reported from Leh-Ladakh and nearby areas in Tibetan Plateau (Pratap & Kapoor 1985, 1987).

The diversity of crop wild relatives in India can be distinctly grouped into different crop groups such as wild relatives of some staple crops like rice [*Porteresia coarctata* (Roxb.) Tateoka, *Oryza granulata* Nees et Arn. ex Watt, *O. meyeriana* var. *inandamanica* J.L. Ellis Veldkamp, *O. minuta* J.Presl, *O. nivara* S.D.Sharma & Shastry, *O. officinalis* Wall. ex Watt, *O. rufipogon* Griff., etc.], wheat (*Triticum sphaerococcum* Percival and *T. compactum* Host) and millets [*Eleusine indica* (L.) Gaertn., *Sorghum arundinaceum* (Desv.) Stapf, *S. controversum* (Steud.) Snowden, *S. deccanense* Stapf ex Raizada, *S. nitidum* (Vahl) Pers., etc.]. Similarly, the unusual diversity of grain legumes, i.e. *Cajanus* (15 species), provides the strong genetic backup for the future-breeding programme. Similarly, oilseed crops [e.g. *Brassica napus* subsp. *napus* var. *quadrivalvis* (Hook. f. & Thom.) O. Schulz, *B. tournefortii* Gouan, *B. rapa* var. *trilocularis* Hanelt, *Carthamus lanatus* L., *C. oxyacantha* M. Bieb., *Lepidium capitatum* Hook.f. & Thomson., *L. draba* L., *Sesamum alatum* Thonn., *S. malabaricum* Burm., *S. radiatum* Schumach. & Thonn., etc.], fibre crops [e.g. *Boehmeria malabarica* Wall. ex Wedd., *B. macrophylla* Hornem., *B. platyphylla* D.Don., *Corchorus depressus* (L.) Stocks, *C. capsularis* L., *C. fascicularis* Lam., *Crotalaria retusa* L., *C. pallida* Aiton, *C. paniculata* Willd., etc.], forage crops [e.g. *Bothriochloa intermedia* (R.Br.) A.Cam, *B. pertusa* (L.) A. Camus, *Chloris bournei* Rang. & Tadul., *C. montana* Roxb., *Eragrostis curvula* (Schrad.) Nees, etc.], vegetables [*Abelmoschus angulosus* Wall. ex Wight & Arn., *Canavalia cathartica* Thouars, *Cucumis callosus* (Rottler) Cogn., *Luffa echinata* Roxb., *Momordica cymbalaria* Hook.f., *Solanum vagum* Heyn. ex Nees, *Trichosanthes dioca* Roxb., *Chenopodium album* L., *Malva sylvestris* L., *Allium carolinianum* DC., *Alocasia cucullata* (Lour.) G.Don., *Dioscorea glabra* Roxb., etc.] and fruits and nuts [e.g. *Actinidia strigosa* Hook.f. & Thomson (Actinidiaceae), *Malus baccata* (L.) Borkh., *Pyrus polycarpa* Hook.f., *Ribes nigrum* L., *Rubus paniculatus* Sm., *Sorbus lanata* (D.Don) S.Schauer, *Artocarpus heterophyllus* Lam., *Citrus indica* Yu.Tanala, *Cordia gharaf* Ehrenb. ex Asch., *Elaeagnus kologa* Schltdl. *Garcinia indica* (Thouars) Choisy, *Musa acuminata* Colla]. India in general and South India in particular (especially Kerala) has been referred to as the land of spices. Moreover, India is believed to be the centre of origin of ginger and turmeric. One species of cardamom [*Elettaria cardamomum* (L.) Maton] and its closest wild relative *E. ensal* (Gaertn.) Abeyw. is also found in Western Ghats. The diversity of spices and condiments in India has been found to be maximum in *Ammomum* (8 species), *Cinnamomum* (10 spp.), *Turmeric* (28 spp.), nutmeg (4 spp.), pepper (22 spp.), vanilla (3 spp.) and ginger (17 spp.) (Nayagam et al. 1993; Kumar & Raju, 1998; Arora 2000; Paulsamy et al. 2010; Singh 2020).

Similarly, the wild relatives of commercial crops such as coconut, coffee, rubber, sugarcane, tea and various wild varieties of medicinal and aromatic plants (81 species) including many genera such as *Allium*, *Dioscorea*, *Phyllanthus*, *Solanum*, *Mucuna*, etc. are found in India. Vast numbers of floriculture species are also documented from India, for example, more than 100 spp. of *Rhododendron*, 1434 spp. of orchids, 43 spp. of *Primula*, 20 spp. of *Lonicera*, 14 spp. of *Aster*, 64 spp. of *Begonia*, 241 spp. of *Impatiens*, 73 spp. of *Iris,* 43 spp. of *Jasminum,* 24 spp. of *Hedychium*, 7 spp. of *Pandanus,* 37 spp. of *Ixora,* 14 spp. of *Gardenia,* 12 spp. of *Crinum,* 11 spp. of *Lilium,* 26 spp. of *Barleria,* 37 spp. of *Ipomoea,* 14 spp. of *Tabernaemontana*, 10 spp. of *Thunbergia* and 37 spp. of *Bauhinia* from India (Singh 2020).

Systematic efforts have been made to compile information on lesser-known food plants including wild resources used by farmers and tribal communities in different regions of the country. Ethnobotanical investigations conducted in various parts of the country reveal that a large number of wild plant species are being used by natives to meet their varied requirements (Jain and Sinha 1987; MEF 1994; Jain and Tiwari 2012).

However, given the resources, it is not possible to work on all the useful species, and there is a need for prioritization. The choice of species including their relative priority has to be clearly highlighted. In this context, it may be added that the underutilized food crop plants given research priority in India include pseudo-cereals and minor millets, minor grain legumes, fodder and energy plantation crops and some high-value industrial plants.

5.4 Underutilized Crops

When we talk about food production and food security, we usually think about just a handful of the main grains: wheat, rice and maize. But many underused crops that are often more nutritious and are able to grow better in adverse conditions are neglected (Blench 1997). They could also help fight climate change because they often need less water and tolerate higher temperatures and droughts. There are plenty of other grains, like sorghum and millet in Africa and South Asia; quinoa in Latin America; and Tef which is a favourite in Ethiopia. Additionally, there is also a huge number of underutilized fruit, vegetable and tuber crop species. Tubers like cassava, *Ensete*, *Amorphophallus*, *Dioscorea* and sweet potato are hugely important survival crops for poor people in tropical countries but are terribly under-researched. They come in endless varieties, and many of them are grown only in a few places but may have unique qualities the whole world could use (Bhag and Joshi 1991; Bhag 1994; Bhatt et al. 2009). We have sorghum varieties rich in zinc, pearl millet rich in iron and yellow flesh potatoes rich in vitamin A. They are agricultural remedies for nutritional maladies. Like other important crops, these neglected and underutilized plants are also categorized under cereals, pseudo-cereals, legumes, fruit crops, root crops, medicinal plants, etc. (Mishra et al. 2016). Those unexploited and underutilized crops are more resilient to adverse climate and varied edaphic factors in India. However, these plants need more genetics and molecular understanding for improvement and better marketing and extension support. Development in unexploited crop cultivation techniques can be achieved either through approaches that take different types of methods for selection, hybridization and metamorphosis breeding or through bioinformatics or molecular approach which includes marker specific, i.e. MAB (Marker-Assisted Breeding) and TILLING (Targeting-Induced Local Lesions in Genomes) (Mishra et al. 2016). Several challenges lie ahead of biotechnologists as well as molecular biologists for improving the underutilized crops in India (Mishra et al. 2016). Underutilized crops are grown on more than 250 million ha in developing countries (Naylor et al. 2004). For improving and achieving more nutrient value, they require a definite molecular and bioinformatics platform as well as confirmed genetic dataset resource on large scale.

5.5 Underutilized Fruits

India is blessed with great diversity and an abundance of underutilized fruit crops. These are often the only source of protective food and source of vitamins and minerals for indigenous people (Kalita et al. 2014). These fruits have been utilized for ages in the traditional system of medicine—Ayurvedic and Unani systems (Mitra et al. 2010). Some underutilized fruits in India are *Phyllanthus emblica* L., *Feronia limonia* (L.) Swingle, *Aegle marmelos* (L.) Corrêa, *Syzygium cumini* (L.) Skeels, *Ziziphus mauritiana* Lam., *Ficus carica* L. (Vino and Harshita 2016), *Averrhoa* *carambola* L., *Dillenia indica* L., *Elaeocarpus floribundus* Blume, *Phyllanthus acidus* (L.) Skeels, *Artocarpus heterophyllus* Lam., *Baccaurea sapida* (Roxb.) Müll.Arg., *Flacourtia jangomas* (Lour.) Raeusch., *Carissa carandas* L., *Spondias pinnata* (L. f.) Kurz (Das et al. 2009), *Grewia asiatica* L. (Mitra et al. 2010), *Malpighia glabra* L., *Mangifera andamanica* King, *Morinda citrifolia* L., *Syzygium aqueum* (Burm.f.) Alston, *Annona squamosa* L., *A. muricata* L., *Averrhoa bilimbi* L. and *Ficus racemosa* L. (Singh et al. 2012a, b) (Plate 5.1).

5.6 Underutilized Grasses and Sedges

Grasses and sedges are also useful from the perspective of biomass and some medicinally important phytochemicals; however, they too are neglected and not utilized as per their potential. *Arundo donax* L., *Desmostachya bipinnata* (L.) Stapf., *Saccharum munja* Roxb., *S. spontaneum* L, *S. bengalense* Retz. and *Vetiveria zizanioides* L. Nash are useful in bioenergy production and ecological restoration (Awasthi et al. 2017). However, *Cynodon dactylon* (L.) Pers., *Pycreus flavidus* (Retz.) T. Koyama, *Digitaria sanguinalis* (L.) Scop., *Bulbostylis barbata* (Rottb.) C.B.Clarke, *Cyperus difformis* L., *Cyperus rotundus* L., *Fimbristylis cymosa* R.Br., *F. eragrostis* (Nees) Hance, *F. monostachya* (L.) Hassk., *Paspalidium flavidum* (Retz.) A. Camus and *Scleria lithosperma* (L.) Sw. are a useful source of nutrients and secondary metabolites (Babu and Savithramma 2013, 2014).

5.7 Conservation

As a recent report on Global Biodiversity Outlook indicates, progress and commitments were insufficient to achieve the Aichi Biodiversity Targets by 2020 (CBD 2020). The world fails to meet biodiversity conservation goals, and the list of rare and threatened species continues to grow. It is estimated that two in five species in the world are threatened with extinction (Antonelli et al. 2020). We are falling too short in our attempts to conserve biodiversity. The reasons for this situation are multiple and complex, including scientific, technical, sociological, economic and political factors. Some in the conservation community believe that saving all existing biodiversity is still an achievable goal. On the other hand, there are those who believe that we need to accept that biodiversity loss will inevitably continue, despite all our conservation actions, and that we must focus on what to save, why to save and where to save. It has also been suggested that we need a new approach to conservation in the face of the challenges posed. We need to take necessary steps to make our conservation protocols more explicit, operational and efficient so as to achieve the maximum conservation effect.

We need to give top priority to the conservation and sustainable utilization of underutilized, neglected and threatened plants that the local rural populations depend

Aporosa cardiosperma (Gaertn.) Merr. Photo by KA Sujana

Artocarpus altilis (Parkinson ex F.A.Zorn) Fosberg Photo by KA Sujana

Baccaurea courtallensis (Wight) Müll.Arg. Photo by KA Sujana

Cordia wallichii G.Don Photo by KA Sujana

Ficus racemosa L. Photo by KA Sujana

Flacourtiajangomas (Lour.)Raeusch. Photo by KA Sujana

Plate 5.1 Some underutilized edible fruits

on. In view of large-scale over-exploitation of land-use practices, ecosystems or parts of them are under threat throughout the country. The conservation of such plant species assumes great priority for current and future use in extreme climatic conditions and those with rich biodiversity regions. Domestication for cultivation may have to be initiated in areas where the climatic conditions are similar to the niche of wild species. Valuable germplasm of underutilized plant species is maintained by the

BSI (Botanical Survey of India) and its botanic gardens in regional centres located in different climatic zones of the country—NBPGR (National Bureau of Plant Genetic Resources), New Delhi, and its regional stations, NBRI (National Botanical Research Institute), CIMAP (Central Institute of Medicinal and Aromatic Plants) and CDRI (Central Drug Research Institute), Lucknow, JNTBGRI (Jawaharlal Nehru Tropical Botanical Garden and Research Institute), Palode, Kerala, etc. The majority of the germplasm, seed and propagule collections are maintained through periodic regeneration. MOEFCC has assisted in creating 15 lead botanic gardens in various parts of the country. Around 38 important gardens spread across India are actively conserving and propagating around 5000 plant species. AJC Bose Indian Botanic Garden, established in 1787 at Kolkata, has around 15,000 live collections representing around 1400 species (Singh and Dash 2017).

In molecular aspects, the plants' genomic approaches have shown that several plastid genes are more conserved over evolutionary time than what was previously presumed (Mahalakshmi et al. 2002, Matthews et al. 2003. Caetano-Anolles 2005, Jaiswal et al. 2006). These conclusions indicate that the model crop system can be formed after recommended improvements to other food crops. *Arabidopsis thaliana, O. sativa* (rice), *T. aestivum* (wheat) and *Zea mays* (maize) are some examples where a complete plant genome is accessible (Paterson et al. 2005; Varshney et al. 2007).

5.8 Recommendations

To make our food systems more robust for the future, we must diversify the spectrum of species used, protect biodiversity and safeguard essential ecosystem services that maintain soil and water quality. The focus must be on utilizing local species and sustaining local agriculture as a means of supporting livelihood and achieving food and nutrition security. Unexploited or underutilized species are better adapted to local conditions, have higher genetic diversity and are essential to the livelihoods of millions of people. In identifying research and development issues that should be addressed, it is essential to approach the problem from different perspectives. One aspect is to convert an underutilized plant into some modern high-value commodity. Another aspect is more appropriate to a community's real needs and concerns. One key strategic element involves the deliberate attempt to explore how conservation and utilization can be combined to secure the resource base of such species. The approaches may differ, depending on whether the species is seed propagated or clonally propagated, annual or perennial, outbreeding or self-pollinated. However, the basic questions remain the same! What is the smallest size of ex situ collection that can cover substantial amounts of diversity and how can it be most economically maintained? How much diversity will remain in production systems and how can this be monitored? How can resources be secured through linkages and collaborations, involving producers, consumers and the formal and informal sectors, to ensure that both conservation through use and conservation for use can be sustained? New technologies (e.g. molecular genetics and geographical information systems) will certainly play their part in the process of developing conservation and use strategies (Young et al. 1999). Perhaps there needs to be some deliberate determination of the way in which these powerful tools can be best used for such plants. There is also much work to be done on the development of sustainable linkages between organizations, growers and consumers. It will always be unlikely that any one organization will have the resources to support the work and research required on a large scale. A major challenge is how to make these networks perform efficiently and in a sustainable manner. Strengthened community involvement in the management of underutilized plant resources and deliberate attention to their needs for new and existing resources will provide the basis for future work on key production issues. The first of these is obviously the development of improved materials. Similarly, participatory approaches may be essential to resolving other production and marketing constraints. Ultimately, we have to recognize that underutilized plants present their own range of problems and opportunities. These are important to many farmers in ways that are complementary to and different from their concerns for the major plants. Developing an agenda specific to these important but neglected plants must be recognized as an important and continuing need.

Multipurpose neglected and underutilized species from different regions, such as those identified by various national institutes and universities, would be key to shaping more sustainable and diversity-driven agriculture in the future while safeguarding ecosystems and the services they provide. However, if such foods are to compete in the existing marketplace (which is dominated by a few commodity crops), agricultural subsidies and incentives will need to be extended to these new initiatives.

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Part III
Faunal Diversity

Chapter 6
Status, Issues, and Challenges of Biodiversity: Invertebrates

Kailash Chandra and Chelladurai Raghunathan

6.1 Introduction

Biodiversity outlines the combinations of all sorts of living organisms with their intrinsic variabilities across the different ecosystems of the world. It is the foundation as services providers for the maintenance and sustainability of the entire ecosystems in terms of ecology, biology, physiology, economy, etc. The studies on the fossil records and paleological evidence suggested that the evolution of animal life took place during the Precambrian period which is known as the Ediacaran period, i.e., between 635 million years ago and 543 million years ago (late Proterozoic (Neoproterozoic) Era). The life of that period was termed as Ediacaran biota which evolved from protists, while it is believed that the maximum diversity of the invertebrates was recorded during the Cambrian period, i.e., 530 million years ago which is also termed as the Cambrian explosion (Gould 1989; Conway Morris 1997; Collen et al. 2012). This period is known remarkably for the rapid process of evolution and origin of new animal phyla. The changes in environmental parameters like temperature and moisture as a result of continental plate movements facilitated the animal communities for the development of features and adaptation as per the habitat, while Cenozoic Era is known for the development of new niches for several groups of organisms.

The Kingdom Animalia is comprised of 34 phyla that thrive across the world. Apart from the Subphylum Vertebrata under the Phylum Chordata, all the animal groups are considered as invertebrates. The recent database of the animal kingdom suggested a total of 1,637,932 valid and extant species under all the 34 phyla, while India represents 102,161 species under 28 phyla (excluding Placozoa, Xenacoelomorpha, Orthonectida, Cycliophora, Gnathifera, and Priapulida) which

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Table 6.1 Invertebrate faunal diversity of India and the world

S. No.	Phyla	Global database	Indian database	Percentage of species occurrence
1	Phylum Porifera	9324	550	5.90
2	Phylum Placozoa	3	0	0.00
3	Phylum Cnidaria	11,973	1453	12.14
4	Phylum Ctenophora	202	19	9.41
5	Phylum Xenacoelomorpha	454	0	0.00
6	Phylum Chaetognatha	132	44	33.33
7	Phylum Platyhelminthes	24,600	1789	7.27
8	Phylum Gastrotricha	855	163	19.06
9	Phylum Dicyemida	122	6	4.92
10	Phylum Orthonectida	25	0	0.00
11	Phylum Nemertea	1329	8	0.60
12	Phylum Mollusca	95,671	5227	5.46
13	Phylum Sipuncula	157	41	26.11
14	Phylum Annelida	13,906	1082	7.44
15	Phylum Entoprocta	197	10	5.08
16	Phylum Cycliophora	2	0	0.00
17	Phylum Gnathifera	1	0	0.00
18	Phylum Gnathostomulida	100	1	1.00
19	Phylum Rotifera	2014	467	23.19
20	Phylum Acanthocephala	1420	306	21.55
21	Phylum Phoronida	13	3	23.08
22	Phylum Bryozoa	6405	337	5.26
23	Phylum Brachiopoda	414	8	1.93
24	Phylum Nematoda	11,030	2984	27.05
25	Phylum Nematomorpha	356	20	5.62
26	Phylum Kinorhyncha	300	10	3.33
27	Phylum Priapulida	22	0	0.00
28	Phylum Loricifera	37	1	2.70
29	Phylum Tardigrada	1229	31	2.52
30	Phylum Onychophora	202	1	0.50
31	Phylum Arthropoda	1,325,303	76,461	5.77
32	Phylum Echinodermata	7444	784	10.53
33	Phylum Hemichordata	130	14	10.77
34	Phylum Chordata (except vertebrates)	3305	537	16.25
	Total number of species	1,518,677	92,357	6.08

is 6.02% of the global species (WoRMS 2020; GBIF 2020; MolluscaBase 2020; Catalogue of Life 2020). The systematic arrangement of the phyla is prepared based on Telford et al. (2015), Crustacea (2016), and WoRMS (2020). The invertebrate database of India represents a total of 92,357 species against 1,518,677 species of the world with a share of 6.08% (Table 6.1). The possible systematic arrangement of all

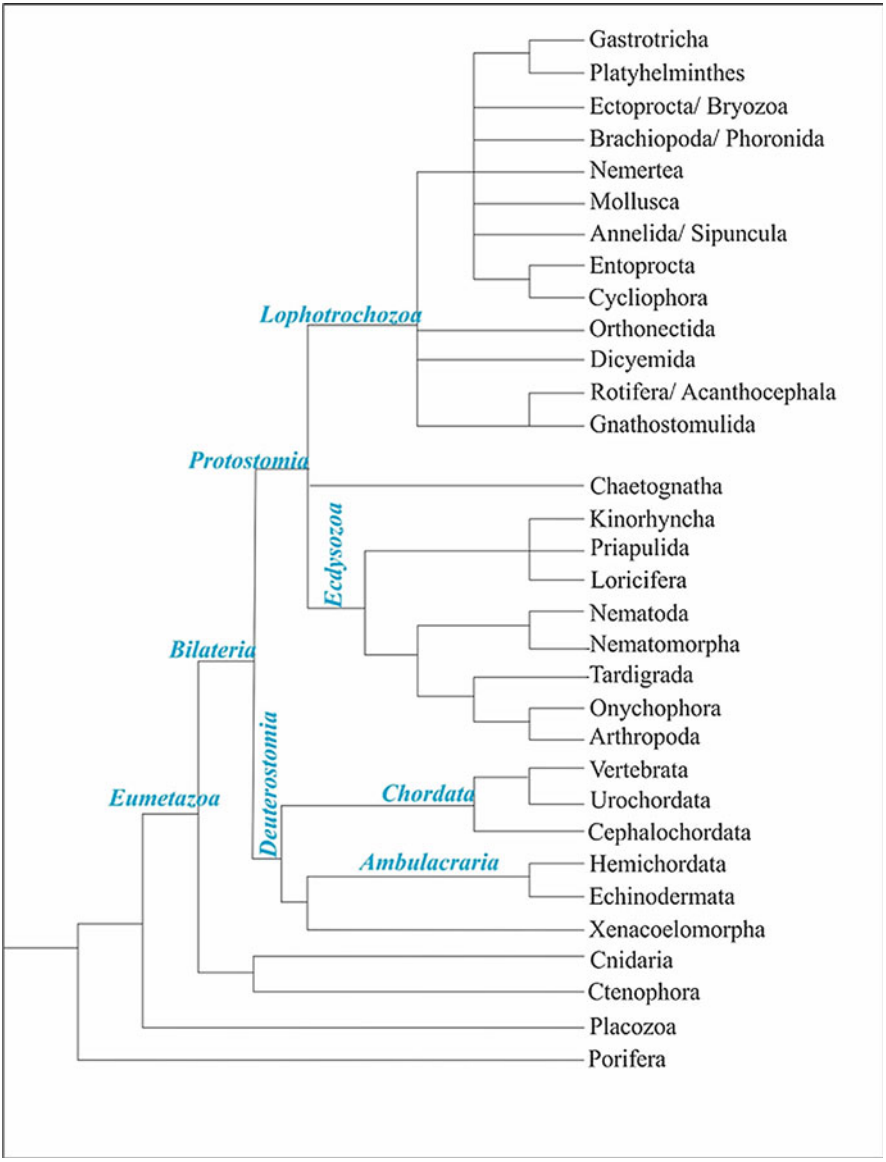

Fig. 6.1 Possible systematic arrangement scheme of Animal Kingdom (adapted from Crustacea 2016; WoRMS 2020)

the animal phyla is made based on the abovementioned references (Fig. 6.1). The invertebrate diversity in different phyla is discussed below.

6.2 Phylum Porifera

The Phylum Porifera are commonly known as sponges representing pores in their body organization and are considered the most primitive metazoans with the sessile mode of life (Müller 1995). These animals are filter feeders and feed on plankton and organic particles through the process of filtration. The adults are sedentary, while larval forms are known as sessile forms. Porifera does not represent tissue, but it has cells with specialized functional features for feeding, protection, etc. The faunal representatives under this phylum are distributed across the world's oceans from temperate to tropical as well as polar regions (Dayton et al. 1974; Hiscock 1983; Picton 1990; Diaz et al. 1990), while only 1% of species are reported from freshwater ecosystems. They are taking a substantial role in the coral reef ecosystems in terms of ecological functions through commensalism, mutualism, competition, host of several species, and important source of several compounds with greater pharmaceutical significance. The studies on the sponges in India were initiated by Carter (1880, 1881) and followed by several workers like Dendy (1887, 1889, 1916a, b), Schulze (1902, 1904), Annandale (1914, 1915a, b), Dendy and Burton (1926), Burton (1928, 1930, 1937), Burton and Rao (1932), Ali (1956), Thomas (Thomas 1968a, b, c, d, e, Thomas 1970a, b, c, 1972, 1974, 1975, 1976, 1977, 1979, 1980a, b, 1984, 1985), Thomas et al. (1996), Pattanayak (1998), Subba Rao and Sastry (2005), Prabhakaran (2008), Immanuel and Raghunathan (2011), Pattanayak and Mitra (2013), Sivaleela et al. (2013, 2014), Vinod et al. (2014), Immanuel et al.(2015), and Ubare and Mohan (2016) who reported sponges in different regions of Indian seas. Presently, 9324 species of sponges are recorded from marine and freshwater ecosystems of the world including 794 species under the Class Calcarea, 7718 species under the Class Desmospongia, 685 species under the Class Hexactinellida, and 126 species under the Class Homoscleromorpha (Van Soest et al. 2020), whereas India contributes only 550 species.

6.3 Phylum Placozoa

Placozoans are considered the most primitive metazoans and originated during the Ediacaran eon (635–542 Ma) or Cryogenian era (720–635 Ma) (Cabej 2020). Placozoans are commonly known as flat animals (Wehner and Gehring 2007). This faunal group is free living with a very simple structural organization. The study on placozoa was initiated by Schulze (1883) and Barnes (1982). The morphometry of this group of animals is represented by an irregular outline with an epithelium layer (enclose a mesenchymal syncytial net) along with cilia, flattened upper surface, and concave lower surface (Brusca and Brusca 2003). The presence of cilia helps the animals with the gliding movement (Schulze 1883). The distribution of the placozoans is restricted to the tropical and subtropical marine realms of the globe mostly near the shore and littoral zones (Voigt et al. 2004; Pearse and Voigt 2007; Schierwater et al. 2011). Only three species of placozoans such as *Trichoplax adhaerens* (Schulze 1883); *Hoilungia hongkongensis* and *Polyplacotoma mediterranea* are considered as the valid and extant species across the world (Schierwater et al. 2020; WoRMS 2020), while it is believed that around 80 species of placozoans are existing in nature (Schierwater et al. 2020). Till now there is no report of any species of placozoans from Indian waters.

6.4 Phylum Cnidaria

The faunal communities under the Phylum Cnidaria represent a wide range of animals which are commonly known as hard corals, soft corals, hydroids, jellyfishes, sea anemones, encrusting anemones, sea fans, black corals, sea pen, jewel anemones, tube anemones, jewel anemones, blue coral, etc. These faunal communities are radially or bilaterally symmetric and harbor diverse faunal communities with extremely composite cellular products, i.e., Cnida. The presence of cnidocytes among this faunal group helps them for food capture. They have two body forms such as medusa (swimming) and polyp (sessile). These are mostly found in marine habitats, while some are recorded in freshwater ecosystems also. These animals are distributed from the intertidal region to the greater depth of the oceans. Cnidarians are contributing to the formation of coral reefs of the world which are an extremely fragile ecosystem and have been known for millennia. In India, the studies on the cnidarians were initiated with the work of Browne (1905, 1906, 1916) and followed by Annandale (1916), Rao, Panniker and Nair (1946), Panikkar and Prasad Jones, Mansueti, and Raghunathan and Srinivasan (1983). The recent estimation of the species database indicates a total of 11,973 species of cnidarians across the world (WoRMS 2020), while the Indian database implies a total of 1453 species.

6.5 Phylum Ctenophora

The commonly known comb jellies, sea walnuts, sea gooseberries, or Venus's girdles are representing the Phylum Ctenophora. Generally, these free-swimming animals are transparent in appearance with delicate gelatinous confirmation. These animals are distributed across the world's oceans from the surface region to the greater depth of around 3000 m (Brusca and Brusca 2003; Mills 2010; Wrobel 2012). These bilaterally symmetrical animals are with comb-like eight ciliary plates which help them in locomotion (Brusca and Brusca 2003). The studies on the Ctenophores in Indian waters were carried out by Annandale and Kemp (1915), Menon (1927), Varadarajan (1934), Devanesan and Varadarajan (1939, 1942), Chacko et al. (1954), Anantaraman (1959), Robin et al. (2009), Srichandan et al. (2013), and Fuad and Padmavati (2017). Based on the available literature, it is found that a total of 202 species of ctenophores are recorded as valid and extant species (WoRMS 2020) while 19 species are from Indian waters.

6.6 Phylum Xenacoelomorpha

The individuals under the Phylum Xenacoelomorpha are represented by a simple and small group of bilaterally symmetrical animals (Philippe et al. 2011), while several characters of bilaterally symmetrical animals are not available (Cannon et al. 2016). The morphological attributes indicate this group as soft-bodied animals with a dorsoventrally flattened body, and these are acoelomate in nature. This group of faunal communities is almost exclusively reported from the marine ecosystem of the world. This group was initially considered as primitive Platyhelminthes, and the ideology was changed during the 1960s based on the studies on the detailed structural organization. The studies on the Xenacoelomorpha are very limited, and this group suggests a great scope for future research due to properly unsolved status in Animal Kingdom (Dunn et al. 2014; Cannon et al. 2016) with the debate of two different kinds of hypotheses such as sister group of Nephrozoa or separate clade under Deuterostomia (Hejnol et al. 2009; Philippe et al. 2011; Srivastava et al. 2014; Cannon et al. 2016). The phylum plays an immense role in the understanding of the evolutionary mechanism of bilaterian cell types and organ systems (Hejnol and Pang 2016). The global database suggested a total of 454 recorded species (WoRMS 2020); however, there are no species reported from Indian water to date.

6.7 Phylum Chaetognatha

Chaetognaths, exclusively marine planktonic forms, are commonly known as arrow worms or glass worms. The shape of the body is like a torpedo. The body is bilaterally symmetrical and divisible into the head, thorax, and tail with sizes ranging from 1 mm to 12 cm (Brusca and Brusca 2003). These faunal communities are available in all the marine habitats of the world including some estuarine habitats from polar to tropical regions (Brusca and Brusca 2003; Margulis and Chapman 2010; Shapiro 2012). Slabber (1778) was the first person to describe Chaetognath. The group was considered separate by Leuckart (1854). The systematics of this group was under debate, and Leuckart and Gegenbaur consider this group between Nematoda and Annelida, while it was placed with Ectoprocta, Phoronida, and Brachiopoda by Butschli. The studies on the Chaetognaths in Indian waters were carried out by John (1933, 1937), Lele and Gae (1936), Subramaniam (1940), Varadarajan and Chacko (1943), Pillai (1944), Menon (1945), Chacko (1950), George (1952), Prasad (1954), Silas and Srinivasan (1968, 1969, 1970), Srinivasan (2007), Nair and Rao (1973), Nair (1977), Divakaran et al. (1980), Jacob et al. (1981), Haldar (1995), George et al. (1998), Casanova and Nair (1999, 2002), Vijayalakshmi and Gireesh (2010), and Kalaiyarasi. As per WoRMS (2020), a total of 132 species of chaetognaths are reported as valid and extant during the present time, while India shares 44 species.

6.8 Phylum Platyhelminthes

The free-living or parasitic, dorsoventrally flattened and acoelomate organisms are commonly known as flatworms representing the Phylum Platyhelminthes. The body of this group of animals is bilaterally symmetrical and unsegmented with three layers of cell, i.e., triploblastic. The faunal communities under this phylum are comprised of four classes such as Turbellaria (mostly free-living, marine species including some species from freshwater and moist terrestrial environments), Monogenea (ectoparasites of generally fish), Trematoda (flukes which represent internal parasites of many animals such as mollusks and others including humans) and Cestoda (tapeworms—internal parasites among vertebrates). The studies on the Platyhelminthes of Indian context were carried out by Laidlaw (1902), Srivastava (1941) and Chauhan (1943a, b, 1945), Job (1968), Gupta (1968a, b, c, 1979), Gupta and Mehrotra (1970a, b, 1971), Gupta and Miglani (1976), Gupta and Puri (1981), Gupta and Sehgal (1971), Gupta and Khanna (1974), Hafeezullah (1991), Hafeezullah and Dutta (1980), Sreeraj and Raghunathan (2015), Apte and Pitale (2011), Sreeraj et al. (2015), Pitale et al. (2014), Dixit and Raghunathan (2013), and Dixit et al. (2018). As per the recent database, a total of 24,600 valid and extant species are recorded across the world, while India represents 1789 species of Platyhelminthes.

6.9 Phylum Gastrotricha

Gastrotrichs are microscopic in size within the ranges of 0.06–3.00 mm and free-living organisms which are known as one of the major meiobenthic communities. These are commonly known as hairy-backs or hairy-bellies (Chatterjee et al. 2019). The body of these bilaterally symmetrical and acoelomate animals is transparent and divided into two regions as head and trunk (Brusca and Brusca 1990). These animals are available in freshwater, marine, estuarine, and semi-terrestrial ecosystems across the globe (Strayer et al. 2010). The studies on Gastrotricha in the Indian context were initiated by Krishnaswamy (1957), while extensive studies were carried out by several researchers from all areas of India (Ganapati and Rao 1967; Govindankutty and Nair 1972; Rao 1993; Rao and Ganapati 1968a, b; Rao and Clausen 1970;

Nagabhushanam 1972; Kameswararao and Chandramohan 1987; Rajan and Nair 1979; Naidu and Rao 2004; Priyalakshmi et al. 2007; Sanyal et al. 2012; Chatterjee et al. 2019). As per the database of WoRMS (2020), a total of 855 species of gastrotrichs are recorded across the globe as valid and extant species, and India represents 163 species of gastrotrichs.

6.10 Phylum Dicyemida

The faunal communities under the Phylum Dicyemida are reported as the parasites of benthic cephalopods. They are found in the kidney of the cephalopods. They are known as endo-symbionts or endoparasites (Suzuki et al. 2010). The body surfaces of these organisms represent numerous cilia which are important for absorbing nutrients. The life cycle of dicyemids is completed by two stages such as vermiform and infusoriform (Lapan and Morowitz 1975). These faunal communities are found across the marine habitats of the world. Beneden coined the term Mesozoa to address the dicyemid as in middle between Protozoa and Metazoa based on the structural organization of the body. The studies on this group of animals are very limited in Indian waters. Kalavati et al. (1978, 1984) and Kalavati and Narasimhamurti (1980) are the only workers in Indian dicyemid studies from the east coast of India and reported a total of 6 species, while globally 122 species are recorded as valid and extant species (WoRMS 2020).

6.11 Phylum Orthonectida

The faunal communities under the Phylum Orthonectida are exclusively available in marine habitats. These animals are small in size ranging between 50 and 800 μm and spent their life as parasitic forms (Hanelt et al. 1996). The body plan of this microscopic animal is very simple with the worm-like multicellular organization, while the outer layer is with cilia. Orthonectids are distributed in the coastal areas of the north-western and north-eastern Pacific oceans. The sexes are separate in this group (Barnes 1982). This group of animals is commonly found along with other host animals like Platyhelminthes, annelids, mollusks, and echinoderms (Barnes 1982). The studies on this group were initiated by Giard (1877) considering Orthonectida as a class under Mesozoa, while the recent studies separated this group from Mesozoa (Hanelt et al. 1996). The proper position in Animal Kingdom is still debatable, and some hypothesis indicates this group with a close relation with Annelida (Bondarenko et al. 2019). As per the recent database of WoRMS (2020), a total of only 25 species are recorded across the globe, while none of the species is recorded from the Indian context under this phylum.

6.12 Phylum Nemertea

The Phylum Nemertea represents a group of coelomate, and bilaterally symmetrical as well as unsegmented worm-like organisms are commonly known as ribbon worms or proboscis worms. The majority of the animals under this group are free-swimming, which is known as benthic (Brusca and Brusca 2003). They are found in all types of aquatic like freshwater, estuarine, and marine habitats, while they are reported from terrestrial habitats as well (Gibson 2004; Roe et al. 2007). The studies on the nemerteans in the Indian context were initiated by Gravely (1927), while Patel et al. (1976) reported the nemertean from the Gujarat area followed by Desai (2010). Shrinivaasu et al. (2011), Venkataraman et al. (2012), and Raghunathan and Mondal (2018) recorded nemerteans from Andaman and Nicobar Islands. Shynu et al. (2015) recorded nemerteans from Kerala and Tamil Nadu coastal areas, while Shrinivaasu (2016) prepared a checklist of nemerteans from Indian waters. Based on the available literature, a total of 8 species of nemerteans are recorded from Indian waters, while the global database suggests a total of 1329 valid and extant species (WoRMS 2020).

6.13 Phylum Mollusca

The Phylum Mollusca is considered as the most diverse faunal group commonly known as scallops, clams, mussels, snails, slugs, limpets, sea hares, oyster, squids, octopus, ammonites, tusk shells, and chitons and found in marine, freshwater, estuarine, as well as terrestrial habitats with the second largest number of species among the Animal Kingdom. The estimated species diversity suggests 50,000–55,000 species from marine ecosystems, 6000–7000 species from freshwater ecosystems, and 25,000–30,000 species from terrestrial ecosystems (MolluscaBase 2020). These coelomate animals are distributed from the arid desert ecosystems to the greater oceanic trenches of the world. The body of this group of an animal contains the head, foot, and visceral mass as common features among all the eight classes like Bivalvia, Caudofoveata, Cephalopoda, Gastropoda, Monoplacophora, Polyplacophora, Scaphopoda, and Solenogastres. It is estimated that the mollusks evolved 550 million years ago (MolluscaBase 2020). Asiatic Society of Bengal initiated the studies on Indian mollusks followed by Indian. Comprehensive studies were carried out on the Indian mollusk from all types of habitats and ecosystems by several workers. A total of 95,671 species of mollusks are recorded across the world as valid and extant species (MolluscaBase 2020), whereas India contributes 5227 species.

6.14 Phylum Sipuncula

The animals under Phylum Sipuncula are worm-like with unsegmented bodies. These bilaterally symmetrical animals are looking like shelled peanuts which defines their common name as peanut worms. Sipunculates are mostly sharing marine habitats, while some are distributed in estuarine habitat also by forming burrows in sandy or muddy substratum, and some species inhabit in crevices of rocks, coral reefs, as well as empty molluscan shells. They are distributed across the benthic habitats of the entire marine system from tropical to cold regions up to the maximum depth of 6860 m (Schulze 2004). The body of this group of animals is composed of an introvert and a trunk, while the size of the body ranges between 2 and 100 mm. The studies on the sipunculans were initiated with the collections made by Hardwicke in 1828, while earlier studies were made by Shipley (1903). Later, studies on the sipunculans were carried out by Annandale (1907), Gravely (1927), Johnson (1964, 1971), Rajulu and Krishnan (1969), Ganapati and Subba Rao (1970), Rajulu (1975), Reddiah (1975), Haldar (1975, 1976, 1978, 1995), Singhal (1988), Mitra et al. (2010), and Venkataraman et al. (2012). The present database of world Sipuncula suggested the presence of 157 valid and extant species (WoRMS 2020), while India shares 41 species.

6.15 Phylum Annelida

The commonly known ragworms, polychaete worms, earthworms, and leeches are falling under the Phylum Annelida. They are either sedentary or free-living animals. Their body is elongated, bilaterally symmetrical, triploblastic, vermiform, truly coelomate, and segmented (Brusca and Brusca, 1990). These faunal communities are mostly distributed in fresh, estuarine, and marine waters, while some are found in terrestrial regions. They are known as burrowing or tubicolous animals. The studies on the Indian leeches were initiated by Harding and Moore (1927), while some other workers such as Baugh (1960a, b), Bhatia (1930, 1939, 1940), Chelladurai (1934), Sanjeeva Raj (1951, 1953, 1954, 1959, 1974, 1981), and Chandra (1973, 1974, 1977, 1978a, b, 1981, 1983, 1984) made a substantial contribution. Based on the recent evaluation, a total of 13,906 species of annelids are recorded across the globe as valid and extant species (Catalogue of Life 2020), while India reported 1082 species.

6.16 Phylum Entoprocta

The Entoprocta is a usually sessile group of organisms found either solitary or colonial mostly in marine ecosystems, while two species are reported from freshwater ecosystems across the world except for Antarctica ((Brusca and Brusca 2003). The size of the body ranges between 01 and 7 mm (Brusca and Brusca 2003). The studies on the Entoprocta in Indian waters were carried out by Annandale (1912, 1916) followed by Seshaiya (1944) and Rao (1991a, b, c). The studies on this group of animals in the Indian context are very scanty which is required to be explored substantially. The present database of Entoprocta reveals a total of 197 species including 2 species from freshwater habitat (WoRMS 2020), while India harbors only 10 species of Entoprocta.

6.17 Phylum Cycliophora

The Cycliophora are bilaterally symmetrical with the acoelomate organization. The recording of this platyzoan phylum is a very recent addition to Animal Kingdom and was first described from the mouthparts of Norway lobsters by Funch and Kristensen (1995). These animals are free-living, and the sizes of the adult animals range between 30 and 350 μm with an anterior buccal funnel, oval-shaped body, and acellular stalk at the posterior position with the adhesive disc. The presence of an adhesive disc helps them for the firm attachment with the host animal's mouthparts. A thin cuticle is present on the trunk and adhesive disc. The distributions of this phylum are restricted to the northern hemisphere only and are recorded from the inter-tidal region to the depth of 720 m. Only two species of cycliophores such as *Symbion pandora* Funch and Kristensen, 1995 and *Symbion americanus* Obst et al. (2006) are described till now from the world's oceans (WoRMS 2020), while there is no report of any species from Indian waters.

6.18 Phylum Gnathifera

The systematic position of this group is still controversial. Presently, Gnathifera is considered a separate phylum (WoRMS 2020), while some hypothesis mentions this one as a clade. The presence of a jaw with a complex structure in its pharynx is the major feature for this acoelomate and bilateral symmetrical phylum. Size ranged between 105 and 152 μm for adult individuals, while body is composed of head, thorax, and abdomen. Only one species, i.e., *Limnognathia maerski*, is described under this phylum. There is no report of this species from India.

6.19 Phylum Gnathostomulida

Phylum Gnathostomulida represents a group of small invertebrate faunal communities which are contributing to meiobenthic communities. These acoelomic and hermaphrodite organisms are exclusively marine and found in sandy as well as a muddy substratum. These are commonly known as jaw worms. They are ranging from 0.5 to 1 mm in body length. The Phylum Gnathostomulida was initially described by Ax in 1956. The studies on the gnathostomulids in India were carried out by Rao (1972, 1980), Thilagavathi et al. (2011), Varghese and Miranda, and Mandal. A total of 100 species are reported as extant and valid species (WoRMS 2020), while India harbors only one species.

6.20 Phylum Rotifera

The rotifers are small faunal creatures ranging between 0.1 and 0.5 mm, while some can be seen as 3 mm in length and are commonly found in freshwater, estuarine, and marine habitats, and some are found in soil, leaf litter, dead trees, mosses, etc. as cosmopolitan distribution (Brusca and Brusca 2003; Segers 2007). The rotifers are commonly known as wheel animals or wheel animalcules. The body is composed of three parts such as head, trunk, and foot. The presence of the foot depends on the sedentary or free-swimming mode of life. The majority of this faunal group is planktonic, while very limited species are sessile. They are considered as one of the vital components of the zooplankton and play a crucial role as food for fish. The description of the rotifer was made by Harris, and the phylum name was given by Cuvier. The studies on Rotifera in Indian waters were initiated by Anderson (1889). Several workers also made notable contributions to the rotifers of India some of them are Murray (1906), Brehm (1950), Arora (1963), Dhanapathi (1976), George et al. (2011), sse, Sharma and Sharma (2005, 2014, 2017), Varghese et al. (2006), Varghese and Krishnan (2008), Anitha and George (2016), and Sharma et al. (2017). A total of 2014 valid and extant species of rotiferans are reported across the world (Catalogue of Life 2020), while 467 species are reported from India.

6.21 Phylum Acanthocephala

The Acanthocephala are commonly known as the thorny-headed, or spiny-headed worms. These animals are parasitic, represent retractile proboscis, and are found in the small intestine region. The recent study reveals that these are very closely associated with the Phylum Rotifera and can be considered under the Phylum Rotifera instead of a separate phylum. Acanthocephala follows their life cycle with the help of a minimum of two host animals either vertebrates or invertebrates (de Buron and Golvan 1986; Golvan and De Buron 1988; Roberts and Janovy 2009), and more precisely these are considered obligate parasites of vertebrates. The distributional range of the acanthocephalans can be seen in terrestrial, freshwater, and marine habitats. These faunal communities are a potential source of human infection with parasitic diseases. But it is also important to note that the infection is rare in nature while most of the infections are recorded in wild as well as domesticated animals. The earlier studies on this group of animals were carried out by Redi followed by von Leeuwenhoek with the record of two kinds of acanthocephalans. Koelreuther proposed the 'Acanthocephali' as the name in 1771, while Acanthocephala was coined by Rudolphi. In India, the study on the acanthocephalan was initiated by Thapar, while some remarkable studies were carried out by Chandler, Van Cleave, Bhalerao, Datta, Podder, Kaw, Das, Datta and Soota, Tripathi, Rai, Gupta and Gupta (1986), George and Nadakkal, Gupta and Jain, Gupta and Fatma, Soota and Bhattacharya, Gupta and Fatma, Nadakkal et al., Gupta and Naqvi and Bhattacharya, and Naidu. The studies on the acanthocephalan from the Indian context were mostly carried out on vertebrates. As per recent estimation, a total of 1420 species are recorded from the world (Wikipedia 2020), while India represents 306 species.

6.22 Phylum Phoronida

The Phylum Phoronida is lophophorate commonly called horseshoe worms. These sedentary organisms are exclusively marine and reported up to the depth of 400 m (Hirose et al. 2014; Emig 2014). The body length of these faunal communities varies between 2 and 20 cm, and they form rigid chitinous tubes (Hinton 1987; Emig 2003; Ruppert et al. 2004). This phylum was described by Wright in 1856. The studies on the Indian phoronids are very scanty, and work was initiated by Gravely (1927). Later studies on this group of fauna were carried out by Nair and Shaw and Ganguly and Majumder. Some of the review works were carried out by Raghunathan and Venkataraman, Raghuraman et al., and Raghunathan and Mondal (2018) on the phoronids of Indian waters. The recent database of the globe suggests a total of 13 valid and extant species of phoronids (WoRMS 2020), while only 3 species are reported from Indian waters.

6.23 Phylum Bryozoa

The lophophorate and coelomate organisms under the Phylum Bryozoa are sessile and mostly found in colonial form, while only one species was recorded as solitary form. These animals are commonly known as moss animals mostly recorded from marine habitats, while some are available in estuarine and freshwater realms also (Brusca and Brusca 2003). The pioneer studies on the bryozoans were made by Thornely, while several other workers like Robertson, Daniel (1954), Ganapati and Rao (1968), Ganapati et al. (1969), Rao and Ganapati (1980), Swami and Karande, Nair, Soja (2006), Soja and Menon (2009), Shrinivaasu et al. (2015a, b), and Venkatraman et al. (2019) made notable studies on the bryozoan faunal communities in the Indian context. The recent database of valid and extant species indicates 6405 species of bryozoans across the globe (WoRMS 2020), while India harbours 337 species.

6.24 Phylum Brachiopoda

The group of individuals under the Phylum Brachiopoda are commonly known as lamp shells. These bilaterally symmetrical, lophophorate, and coelomate faunal communities range between 1 m and 9 mm and are categorized under two classes, while the body is composed of three parts, viz., protocoel, mesocoel, and metacoel (Brusca and Brusca 2003). They are filter feeders and depend on the plankton. Brachiopods are found across the world exclusively in marine habitats (Brusca and Brusca 2003). The first study on the brachiopods was made by Retzius. In India, the study on the group was made by Swainson. Later, studies were made by, Mandal and Nandi (1989), Mitra and Mishra (2006), Rao (2008), and Samanta et al. (2014). As per the WoRMS (2020) database, a total of 414 species of brachiopods are recorded across the globe as valid and extant species, while India contributes only 8 species.

6.25 Phylum Nematoda

The body of the nematodes or roundworms is elongated, unsegmented, bilaterally symmetrical, and cylindrical shaped. A stretchy multi-layered collagenous cuticle is present on the body which is apparently thick. These animals are recorded from every possible ecosystem from soil to the sediment of greater depths of the oceanic ecosystems. These are found as free-living as well as parasitic species. They are a notable part of meiobenthic communities and take significant characters in the re-mineralization process of organic matter and the cycling of essential elements. They are used as brilliant bio-indicators for the assessment of the status of ecosystem health. Extensive studies were carried out on the nematodes in the Indian context by Govindankutty and Nair (1966), Rao and Ganapati (1968a, b), Sukul (1969), Damodaran (1973), Damodaran (1973), Baqri and Khera (1976), Ansari (1978), Khan (1986), Ansari et al. (1980, 2012a, b, c, 2013a, b, c, 2015a, b, c; 2018), Rahman et al. (1993), Ansari and Parulekar (1993, 1998), Altaff et al. (2005), Anbuchezhian et al. (2010), Thilagavathi et al. (2011), Sivaleela and Venkataraman (2013), Sivaleela (2016), Balasubramanian (2017), and Naveen Babu et al. A total of 11,030 species of nematodes are accepted as valid and extant species across the world (WoRMS 2020), while India represents 2984 species.

6.26 Phylum Nematomorpha

The faunal communities under the Phylum Nematomorpha represent the parasitoid group of animals. The larval forms are parasitic and live on arthropods, while the adult forms are free-living (Hanelt et al. 2005). These animals are usually known as horsehair worms or Gordian worms. Nematomorphs are representing two classes such as Nectonematida (the marine forms) and Gordiida (freshwater forms). The cuticle is present at the outside of the body. Studies on Nematomorpha in India are restricted with some reporting only. Studies were carried out by Rajaram and Rajulu (1975), Dasgupta and Khawas (1986), Schmidt-Rhaesa and Yadav (2004, 2013), Schmidt-Rhaesa and Lalramliana (2011), Nongspung (2014), Schmidt-Rhaesa et al. (2015), and Yadav et al. (2017). A total of 356 species are reported from the world (Catalogue of Life, 2020) while India represents only 20 species (Schmidt-Rhaesa et al. 2015, Schmidt-Rhaesa and Lalramliana 2011).

6.27 Phylum Kinorhyncha

Kinorhyncha is a small (usually less than 1 mm), limbless, free-living marine faunal communities, while some are recorded from estuarine habitat also. They are reported from the inter-tidal region to the greater depth of oceans up to 8000 m as part of the meiobenthic communities on the upper sediment layer as eurybenthic fauna (Brusca and Brusca 1990). They need a well-oxygenated sandy layer for their survival, while they are also recorded in algal beds as well as along with other invertebrates like Porifera, Cnidarian, etc. (Brusca and Brusca 1990). The initial study on the Kinorhyncha was carried out by Krishnaswamy (1957). Later, some studies were carried out by some researchers like Timm, Rao and Ganapati, Higgins, Nagabhushanam (1972), Rao (1993), Damodaran (1972), and Dovgal et al. (2008) from India. Globally, 300 species of kinorhyncha are reported as valid and extant taxa (WoRMS 2020), while India represents only ten species.

6.28 Phylum Priapulida

The faunal communities under the Phylum Priapulida are exclusively marine and distributed up to the depth of 90 m in muddy habitat. These cylindrical organisms are commonly called penis worms, while they have an extraordinary capacity to withstand hydrogen sulfide and anoxia (Oeschger and Janssen 1991). The body length of these animals varies between 0.2 and 39 cm (Shirley and Storch 1999). A total of 22 species are recorded under the Phylum Priapulida as valid and extant species (WoRMS 2020), whereas there is no report of any species under this phylum from India.

6.29 Phylum Loricifera

The faunal communities under the Phylum Loricifera are tiny and microscopic in size. These cycloneuralian creatures share marine ecosystems of the world and inhabit the sediment of all depths (Ruppert et al. 2004) including an anoxic environment (Fang 2010; Mills 2010). The phylum was described by Kristensen in 1983. The sediment characters of the residing habitat for the loriciferans can be sandy or muddy. The size of the animals varies between 100 and 800 μm, while the body is composed of the head, mouth, and digestive system (Heiner et al. 2004). A total of 37 species of loriciferans are described, while the estimated species is 100 (Neves et al. 2016). There is only one report of *Armorloricus* sp. (Loricifera: Nanaloricidae) from India as the first documentation of the entire phyla (Annapurna et al. 2017). The documentation was made based on the collected sediment samples from the northeastern coasts of India by FORV Sagar Sampada (Annapurna et al. 2017).

6.30 Phylum Tardigrada

The tardigrades are distributed in all types of aquatic and terrestrial habitats as a cosmopolitan group of faunal communities from the greater depth of the ocean to the greater altitudes across the world including polar regions (Brusca and Brusca 2003; Glime 2010). These animals are commonly known as water bears or moss piglets, and their size ranges between 40 and 1200 μm (Guidetti et al. 2020). These eight lobopodious legged and bilaterally symmetrical animals are tolerant to wide ranges of temperate from 149 to —272 °C which makes them the greatest survivors. The first description of this group of animals was made by Goeze in 1773, while Spallanzani coined the term Tardigrada in 1777. The studies on the tardigrades from India were carried out by Rao (1969), Rao and Ganapati (1968a, b), and Abe and Takeda (2000). A total of 1229 species of tardigrades are reported from the world as valid and extant species (WoRMS 2020), while only 31 species are reported from India.

6.31 Phylum Onychophora

Onychophora are cylindrical, soft-bodied worm-like animals with an average length of between 0.5 and 1.0 cm and 13–43 pairs of legs and smooth texture (Prothero and Buell 2007; Holm and Dippenaar-Schoeman 2010). These animals are commonly called velvet worms (Ruppert et al. 2004). Onychophora is restricted to terrestrial or land ecosystems. These faunal communities represent circumtropical and circumaural distribution. The distribution pattern of this group of animals can be seen based on their two subgroups such as Peripatidae and Peripatopsidae. Species under the group Peripatidae are found in Neotropics, while Peripatopsidae species are reported from the classic Gondwanan region. Sticky secretion is being seen from the onychophorans especially from the paired slime glands which are essential for capturing prey as well as maintaining their self-defense mechanism (Dettner 2010). The importance of this group of organisms is extremely high to understand the biogeography, evolutionary trends, and conservational aspect of animals. There is only one study on Onychophora with the description of *Typhloperipatus williamsoni* Kemp, 1913 made by Kemp (1913) in India. Based on the available published literature, it is found that a total of 202 species of onychophorans are considered valid and extant species.

6.32 Phylum Arthropoda

The Phylum Arthropoda includes an extremely assorted cluster of animals such as tick, mites, spiders, scorpions, sea spiders, centipedes, millipedes, insects, crustaceans, horseshoe crabs, etc. Generally, this group of animals represents a segmented body with an exoskeleton composed of chitin and paired as well as joined appendages. The phylum Arthropoda is known to contribute the maximum species in the kingdom with the ground the cover of 84% of animal species. Due to the greater range of adaptive features, faunal communities under this phylum are distributed across all the habitats as well as ecosystems of the world from the highest of 6700 m to the greater depth of more than 4000 m. In 1848, von Siebold coined the term Arthropoda. This group of animals is known for its immense importance by means of providing a good source of food, ecology, biology, and providing services, as bio-indicator, ecosystem management agents, as the aspect of economic development, etc., while some species are also known for negative impacts. Extremely wide ranges of works were carried out in India on this group of animals based on several abovementioned groups. The present database of the arthropods of the world impels a total of 1,325,303 species (GBIF 2020), whereas in India 76,461 species were reported.

6.33 Phylum Echinodermata

The echinoderms are penta-radially symmetrical organisms and exclusively marine creatures with some species from estuarine habitats. Their vertical distribution reflects wide ranges from intertidal regions to the abyssal region. It is estimated that this group of animals appeared during the Cambrian period. Echinoderms, enterocoelous coelomates, are known to represent a vivid variety of animals under five classes which are commonly known as feather stars, sea lilies, sea stars, brittle stars, sea urchins, sand dollars, and sea cucumbers. Echinoderms are considered deuterostomes and represent more similarities with Chordata in comparison with other invertebrates (Hyman 1955). The term Echinodermata was coined by Klein. The initial study on the echinoderm was made by Plancus and Gualtire (1743) in Indian waters. The studies on the echinoderms in Indian waters were carried out in comprehensive ways by several researchers such as Bell (1887), Wood-Mason and Alcock (1891), Koehler (1927), Clark (1912), Gravely (1927), Daniel and Haldar (1974), James (1991), Sastry (2007), Sastry et al. (2004), Hegde and Rivonker, and Raghunathan et al.. The recent data on the echinoderm database suggests a total of 7444 valid and extant species of echinoderms, while India shares 784 species.

6.34 Phylum Hemichordata

The deuterostome faunal communities under the Phylum Hemichordata with a tripartite body division take a notable role in the understanding of animal evolution (Brown et al. 2008). They are distributed worldwide from sandy or shallow marshy mangrove regions to greater depths of oceanic ecosystems (Cannon et al. 2009; Deland et al. 2010). They are commonly known as acorn worm (faunal communities underclass Enteropneusta which are solitary) or spengel worm (organisms underclass Pterobranchia which are filter feeders) (Swalla and van der Land 2020). The body of these animals is composed of three parts such as proboscis, collar, and trunk. The first account of hemichordate was made by Eschscholtz in 1825, while is the first person to initiate the study on the hemichordates from Indian waters. Later on, studies were carried out by Menon, Rao, Ramanujam, Devanesan and Varadarajan, Kuriyan, Balasubramaniam, and Dhandapani in Indian waters. The recent data on the hemichordates implies a total of 130 valid and extant species across the world (WoRMS 2020), while only 14 species are recorded from Indian waters.

6.35 Phylum Chordata (Only Invertebrate)

The bilateral symmetrical faunal communities with notochord during any point of time of their life cycle are considered under the Phylum Chordata. The basic characters of this group of faunal communities represent a single, dorsal, hollow nerve cord; segmented and coelomic body; and the complete digestive system. These faunal communities are found in all types of habitats in all the latitudes. The fossil record reveals that this group appeared during 541 Mya during the Cambrian period. The Phylum Chordata represent three subphyla such as Cephalochordata, Tunicata, and Vertebrata. Apart from Vertebrata other two subphyla are considered invertebrates in the Animal Kingdom. The world database of the Chordata reveals a total of 122,560 species as valid and extant including 3305 species of invertebrates belonging to 73 species of Appendicularia, 3085 species of Ascidiacea, and 112 species of Thaliacea under Tunicata (Subphylum) and 35 species of Leptocardii under Cephalochordata (Subphylum) (GBIF 2020), while India represents 537 species of invertebrates including 6 species of cephalochordates and 531 species of tunicates.

6.36 Status of Invertebrates

The invertebrates are found both in aquatic and terrestrial ecosystems, while aquatic habitats, covering around 72% of the globe, harbour a greater scale of species diversity (Strayer and Dudgeon 2010). The residing ecosystem defines the status of the taxa based on the physicochemical parameters of the systems. The status of invertebrates in different ecosystems is summarized below.

6.36.1 Freshwater Ecosystem

The freshwater ecosystems are measured with a declining status due to the impact of misuse and pollution which indicates the deterioration in water quality (Dudgeon et al. 2006). Vörösmarty et al. (2010) stated that about 10,000–20,000 species of the freshwater ecosystem are either under the category of extinct or at risk of extinction, especially mollusks, crustaceans, and the odonates (IUCN 2012; Collen et al. 2012). The risk in the freshwater ecosystem directly creates an impact on the survival of the human population by making a gradual reduction in their income which is projected for their livelihood (Collen et al. 2012). The ecosystem cycle and food webs of the freshwater habitats are extensively regulated by the invertebrate faunal communities. Among the invertebrates of the freshwater ecosystem, mollusks are playing a promising role in the maintenance of the entire ecosystem by means of maintaining water quality, maintenance and management of nutrient level, providing food for other groups of faunal communities, maintenance of algal level, etc. (Vaughn et al. 2004; Cuttelod et al. 2011), while some spices are known to provide the greater scale of economic development by means of curio and food (Collen et al. 2012). The larval stages of the odonates are complexly dependent on the freshwater ecosystem. During their course of development, they eat plenty of aquatic insects and perform the role of biocontrolling agents as voracious predators. Changes in water quality are used to destroy the population of the odonates which indirectly indicates the low level of water quality and an increase in harmful organisms in the ecosystem (Trueman and Rowe 2009; Simaika Samways 2011). The species under the group Malacostraca are one of the major contributors among the invertebrates of the freshwater ecosystem. These groups are known for the maintenance of environmental cycles, ecological significance, biological prominence, and economic importance (Dobson et al. 2007). Any changes or disruption in the ecosystem used to make detailed alterations and damages in the niche structure of the Malacostraca population followed by risk of extinction or extinction of species. The freshwater invertebrates of the world are under extreme threats particularly in the Indo-Malayan and Australian biogeographic realms which is due to the prevalence of endemic species along with the increasing threats either naturally or anthropogenic mediated (Collen et al. 2012). The gradual increase in the practice of habitat loss, worsening water quality, overfishing, and changes in climate status are more critical aspects of the damage and threatening of the freshwater ecosystem along with the increase of invasive alien species on native species population.

6.36.2 Marine Ecosystem

The marine ecosystem is the greatest treasure trove of invertebrates of the world as 33 phyla out of 34 are found in this habitat. This ecosystem contributes essentially most of the roles and services for maintaining ecological features of biogeochemical cycles, food webs, physiological processes, and economic benefits. Marine ecosystems of the world cover around 70% of the surface areas of the world along with a greater range of abyssal depth which is providing extremely great deals of habitats for sustaining faunal communities especially invertebrates. Planktons are the major invertebrates of the marine ecosystem. They play a major role in trophic levels. Changes in plankton population or threats to plankton population comprehensively disrupt the food webs followed by the declining trend in population structure. As per the recent estimation, it is found that the maximum threats of 25% on invertebrate species population are recorded on the invertebrates of Southeast Asian and South American waters, while the corals and coral reefs-associated species of Indo-Malay-Philippine realms are under serious threats of extinction as 32% of the hermatypic corals are facing threats of extinction while more than 20% species are under Near Threatened category (Bellwood and Wainwright 2002; Collen et al. 2012).

Coral reefs are very fragile ecosystems that can be seen under threats due to alteration of basic requirements by any means. As the reef-building corals are completely dependent on the symbiotic algae, the changes in environmental factors usually make a greater impact on the symbiotic relationships of corals and zooxanthellate components and resulted in the bleaching event followed by the death or destruction of corals (Shinzato et al. 2011). The corals are the home of around 25% of the marine faunal communities. So, death or depletion of coral's life exponentially destroys the population as well trends of residing species. The gradual process of death and depletion enhances the higher-risk level towards extinction for the invertebrate population. The data analysis of corals reef ecosystem reveals that changes in climate factors made threats of around 19% on stony corals while around 9% threats of depletion were seen due to other activities like development of coastal structure, increased level of pollution in marine habitats, practices of destructive fishing, etc. (IUCN 2008; Collen et al. 2012). The recent estimates suggested that around 90% of the coral reefs will face population depletion by 2030 followed by 100% in 2050 due to all sorts of natural and anthropogenic causes (Burke et al. 2011). The importance of the coral reefs is beyond the imagination and can be seen by means of geochemical cycles, physiological services, ecological services, economic services, biological services, etc. So, the depletion of the population drastically threatens the entire ecosystem.

Mollusks and crustaceans are contributing essentially as the major invertebrate faunal communities which are important for the gross management of marine ecosystems by means of ecological services and biological means, while economic application makes them more preferable for the coastal populations. Coastal areas of the world's oceans are endowed with mangrove, seagrass, and seaweed population along with coral reefs. Changes in the structural organization of the said ecosystems used to make a greater range of disruption in invertebrate population as these ecosystems are considered as a nourishing ground for wide ranges of the animal population, especially invertebrates.

6.36.3 Terrestrial Ecosystem

The invertebrates of terrestrial habitats are distributed among the nine phyla, while the Phylum Onychophora is exclusively found in this ecosystem, and Phylum Arthropoda represents wide range of faunal communities with the maximum number of insects (Collen et al. 2012). Other seven phyla include Nematoda, Platyhelminthes, Nemertea, Annelida, Tardigrada, Acanthocephalan, and Mollusca characterized mostly as soft-bodied, burrowing, worm-like, parasitic groups of faunal communities (Collen et al. 2012). Terrestrial habitats are exposed to extreme ranges of variety and variability in terms of physicochemical parameters, while the invertebrate faunal communities are showing greater ranges of adaptation as well as adaptive radiation by means of habitation. It is estimated that around 8.3 million species of invertebrates are available in nature while only around one million species are described till now (Mora et al. 2011). Terrestrial ecosystems are more prone to face natural as well as anthropogenic threats by means of habitat destruction or alteration, development activities, cyclonic effects, pollution, etc. which make the invertebrate faunal communities more vulnerable. The soft-bodied burrowing invertebrate animals with small ranges of movement capacity are more susceptible against any sort of habitat alteration or ecological as well as physicochemical changes which make them under a higher degree of threats towards population depletion as well as the extinction of species.

As per the recent estimation of IUCN, it is found that a total of 1,504,341 species of invertebrates are described till now. Among them only around 2% of species, i.e., 23,808 species, are evaluated for their status analysis. The record also implies that 5419 species are under the threatened category. The status evaluation of the animals was initiated from 1996 to 1998, and since then it is found that the species database under the threatened category is increasing in progressive ways. The last 15 years' database of IUCN is depicted here to compare the status of the invertebrates, and it is found that each and every year the assessed species and threatened species database is increasing proportionally. In 2006 the assessment of 3978 species of invertebrates was made, and 2101 species were listed under the threatened category, while in 2020 the assessed species is 23,808 with 5419 species under the threatened category (Fig. 6.2). In both, the cases of assessed and threatened species database showed positive linear progression ($R^2 = 0.9829$ and 0.9936, respectively) (Fig. 6.3).

As per the IUCN (2020), the detailed categorization of the invertebrate faunal communities depicts that still now maximum species of insects are evaluated for or assessed to check their status in the present scenario followed by Gastropoda and Malacostraca (Table 6.2). The present tabular form represents the maximum group of invertebrates under respective classes, while some of the groups are not included here. Among these classes, gastropods represented a minimum of 964 species of threatened faunal communities followed by 806 species under class Insecta. In terms of extinct species, it is found that a maximum of 267 species of mollusks are presently extinct followed by 63 species of insects.

6.37 Issues and Challenges

The invertebrates are providing goods and services to the people which in turn are directly associated with the economy. Though they have immense importance in terms of ecology, physiology, and economy, not much emphasis was made for their assessment and evaluation for conservation and management. The ever-increasing human population is the main cause behind the loss of natural environmental clues which leads to the decline of biodiversity. The services of the invertebrate faunal communities are extensively high. Pollination is one of the most important ecological processes, and it is mostly dependent on the invertebrate faunal communities to complete the process. As per the reports of the Food and Agriculture Organization of

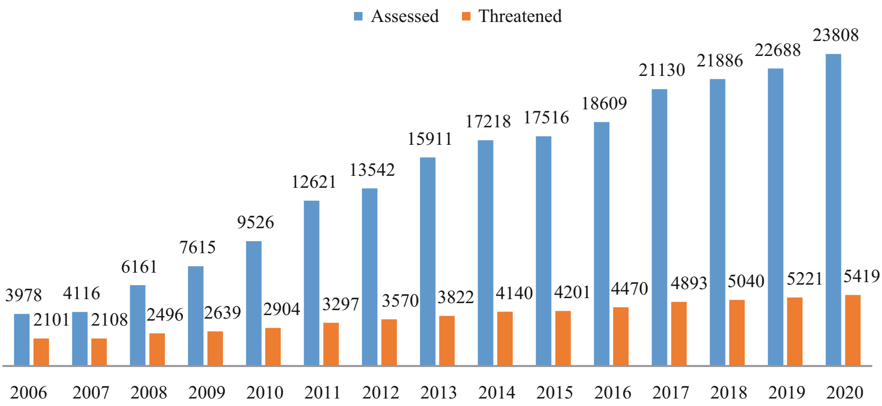

Fig. 6.2 Assessed and threatened invertebrate species database as per IUCN (2020)

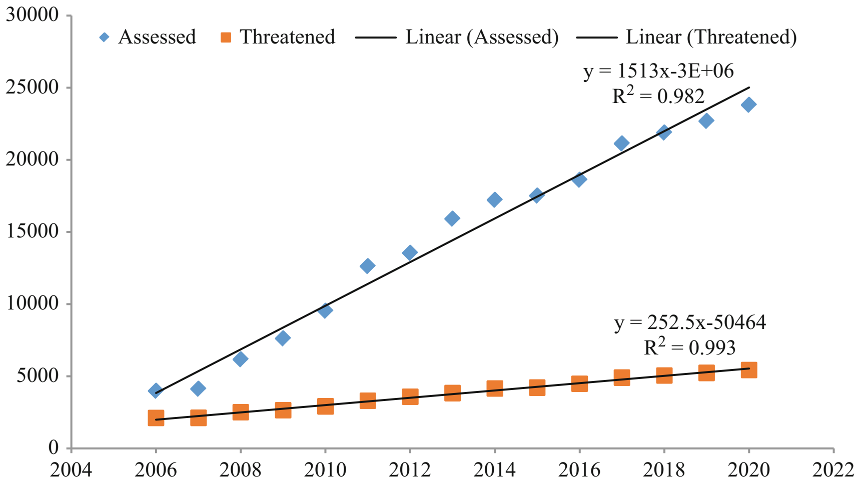

Fig. 6.3 Year-wise trends of assessed and threatened invertebrate species database as per IUCN (2020)

the United Nations (FAO), it is found that 1/3 crop productivity of the world is dependent on the pollination which is carried out by insects and other animals (Collen et al. 2012). These invertebrate faunal communities are the major contributors to the continuation of the bio-geochemical cycle and nutrient cycle of the world including an active role in the decomposition process and enhancement of soil fertility (Collen et al. 2012). These invertebrates are the major components of the food chains of the ecosystem as well as a major source of food for a human being. Apart from these, the invertebrates are known to provide enormous services with the supply of fibers, dyes, mineral materials, bioactive substances, and other materials for pharmaceutical as well as medicinal uses. Some species of invertebrates are

Table 6.2 Details of status of invertebrates as per IUCN category and criteria 2020

Group name	EX	EW	Subtotal (EX + EW)	CR (PE)	CR (PEW)	Subtotal (EX + EW + CR (PE) + CR(PEW))	CR	EN	VU	Subtotal (threatened spp.)	LR/cd	NT orLR/nt	LC or LR/lc	DD	Total
Anthozoa	0	0	0	1	0	1	6	26	202	234	0	175	293	166	868
Arachnida	9	0	9	21	0	30	60	84	53	197	0	10	89	39	344
Bivalvia	32	0	32	15	0	47	77	66	58	201	4	56	338	170	801
Branchiopoda	0	0	0	0	0	0	6	10	22	38	1	1	1	1	42
Cephalopoda	0	0	0	0	0	0	1	2	2	5	0	2	324	419	750
Chilopoda	0	0	0	2	0	2	3	5	1	9	0	0	1	0	10
Clitellata	2	0	2	4	0	6	6	13	8	27	0	12	74	107	222
Diplopoda	3	0	3	4	0	7	34	32	18	84	0	42	37	34	200
Echinoidea	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
Enopla	1	0	1	1	0	2	1	1	1	3	0	0	1	1	6
Entognatha	0	0	0	2	0	2	2	0	2	4	0	2	0	0	6
Gastropoda	267	14	281	134	2	417	598	507	964	2069	0	628	2619	1624	7221
Holothuroidea	0	0	0	0	0	0	0	7	9	16	0	0	111	244	371
Hydrozoa	0	0	0	1	0	1	1	2	2	5	0	1	8	2	16
Insecta	63	1	64	68	0	132	336	677	806	1819	3	594	4752	2561	9793
Malacostraca	7	1	8	17	1	26	138	161	308	607	0	71	1199	1131	3016
Merostomata	0	0	0	0	0	0	0	1	1	2	0	0	0	2	4
Onychophora	0	0	0	0	0	0	3	2	4	9	0	1	0	1	11
Ostracoda	2	0	2	0	0	2	2	0	9	11	0	0	0	0	13
Polychaeta	0	0	0	0	0	0	1	0	0	1	0	0	0	1	2
Turbellaria	1	0	1	0	0	1	0	0	0	0	0	0	0	0	1

Source: www.iucnredlist.org

IUCN Red List categories: *EX* extinct, *EW* extinct in the wild, *CR* critically endangered (includes CR(PE) and CR(PEW)), CR(PE) & CR(PEW): "Possibly Extinct" and "Possibly Extinct in the Wild"; *EN* endangered, *VU* vulnerable, *LR/cd* lower risk/conservation dependent, *NT* near threatened (includes LR/nt—lower risk/near threatened), *DD* data deficient, *LC* least concern (includes LR/lc—lower risk/least concern) playing an important role as biocontrolling agents of the pest species by reducing population.

Despite colossal services and applicability, invertebrates are facing tremendous pressure towards population depletion and extinction. The reasons are described here in brief.

6.37.1 Reduction of Habitat Cover

The growth, development, and sustainability of any species are directly dependent on the space which provides them with habitat. Urbanization, industrialization, plantation, possession of agricultural land, developmental and constructional activities, etc. lead to the loss of biodiversity or natural ecosystems. There are several activities that directly make a reduction in natural habitat cover, while deforestation, grazing, and fire are the most important activities, which destroy the natural ecosystem with greater ranges of devastation (Murray 2002).

6.37.2 Fragmentation of Habitat

Fragmentation in any habitat is a major constraint for the loss of the population of any species. Movement among the animals is found for the search of resources of food and water as well as for the search of mating partners. Fragmentation by means of creating barriers of any means or isolation of landmass from natural habitat or formation of the island used to create a greater impact on the population of the species. The fragmentation reduces the required resources for the animals to survive, while it also shortens the gene pool of the population of any species as mating is being performed with close individuals. The fragmentation is very much detrimental for the endemic species population.

6.37.3 Overexploitation and Harvesting

Nature and natural resources especially biological resources are exploited or harvested in the long past for our survivability. Recently, the depletion of natural resources has been momentously enhanced due to commercial requirements. The commercialization accelerated the demand for natural goods in local and global markets which resulted in the overexploitation and harvesting of those natural biological resources by applying amended harvesting technologies (Murray 2002). Such practice not only destroys any particular species but also damages the entire ecological chain, the ecosystem, as well as biodiversity.

6.37.4 Pollution

Pollution is the major source of devastation and degradation of invertebrates by damaging the entire ecosystem. The discharge of the pollutants from industries and agricultural runoff in the water bodies make severe damages, while the use of pesticides or chemicals in the agricultural field creates a threat to the terrestrial ecosystems.

6.37.5 Invasive Alien Species (IAS)

Bio-invasion is one of the major threats during the recent time due to the arrival and successful establishment of exotic species which can be resulted as Invasive Alien Species (IAS). The successful establishment of the IAS used to destroy the native species population by means of competition for space, food, nutrients, ecological attributes, etc. and make the native species vulnerable. The effect results in a high risk of extinction for the endemic species.

6.37.6 Climate Change

The climatic change is a static and potential threat to the entire biodiversity. Climate change is the major cause of the gradual increase of the world's surface air temperature with an average of 0.6 °C during the last century as per the report of IPCC which resulted in sea level rising about 15 cm during the twentieth century. It is due to melting glacier ice and the expansion of warmer seawater. Increased sea surface temperatures destruct the coral reefs of the world through the process of coral bleaching. Heavier rainfall can be seen as a flood, while the increase in extreme drought, changes in ecosystem structure, frequent cyclonic impact, acidification of seawater, etc. are other impacts. All the changes in natural processes have a direct destructive impact on the population demography of the invertebrates which can be resulted in the destruction of species.

6.38 Mitigation

Since the invertebrate faunal communities are facing tremendous pressures in terms of anthropogenic activities, the growth and development processes are the major reasons for the depletion of biodiversity. Declaration of more protected areas such as National Parks, Wildlife Sanctuaries, Community Reserves, Conservation Reserves, and Biosphere Reserves and Ramsar sites to enhance the scope of natural habitats and forest cover as well as ecosystem. Development of a no-take zone to restrict developmental activities to protect the animals to a considerable extent. Formation of the urban forest, vertical wall, and root-top garden in the city areas to enhance the green cover which will provide notable space for several species of invertebrates to sustain their life. Creating corridors and passageways between the fragmented habitats to help the faunal communities for their free movement and connectivity by means of the natural linking system. Long-term permanent monitoring plots to monitor the life and processes of the invertebrates along with their interaction with the environment. Mapping of the invertebrate population through GIS tool and assessing the threatened species periodically to understand their population status for better conservation.

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Chapter 7
Diversity, Distribution and Endemicity of Herpetofauna in Different Biogeographic Zones and Biodiversity Hotspots of India

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7.1 Introduction

The political boundaries of the Republic of India are known to harbour about 447 species of amphibians and 681 species of reptiles (Gunther 1864; Daniel 2002; IUCN 2020). About 73% of the amphibians and 47% of the reptiles are endemic to the country, i.e. found nowhere else on Earth. Indian herpetofauna is poorly studied with few detailed comprehensive works on their taxonomy, biology, ecology, distribution and conservation. Detailed books and monographs on any groups of Indian herpetofauna are restricted mostly to snakes and some turtles. Lizards, frogs and caecilians have been studied occasionally, mainly regarding the description of new species with hardly any details on their biology and ecology. Keeping these lacunae in mind, an attempt has been made here to document the taxonomic diversity of Indian amphibians and reptiles with the distribution and endemicity of Indian amphibians and reptiles (turtles, lizards and snakes) in the different biogeographic zones and biodiversity hotspots of India (.

There are 406 species of frogs and toads in India belonging to 63 genera and 12 families (Table 7.1). Of these, 292 species are endemic (71.9%). There are 2 species of salamanders and 39 species of caecilians (limbless amphibians) belonging to 5 genera and 3 families. Almost all Indian caecilians are endemic to the country (Table 7.1). Overall, 73.6% of Indian amphibians are endemic making amphibians have the highest percentage of endemicity among all animal groups in India.

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Table 7.1 An overview of taxonomic diversity and status of endemism in amphibians of India

S. No.	Order/suborder/family	India		Endemic species to India
		Number of genera	Number of species	
Order: Anura (frogs and toads)				
01.	Family: Bufonidae	08	29	20
02.	Family: Ceratobatrachidae	01	04	03
03.	Family: Dicroglossidae	12	80	42
04.	Family: Hylidae	01	01	00
05.	Family: Megophryidae	04	28	13
06.	Family: Micrixalidae	01	24	24
07.	Family: Microhylidae	07	31	19
08.	Family: Nasikabatrachidae	01	02	02
09.	Family: Nyctibatrachidae	01	37	37
10.	Family: Ranidae	10	39	22
11.	Family: Ranixalidae	02	18	18
12.	Family: Rhacophoridae	15	113	92
Order: Urodela (salamanders)				
13.	Family: Salamandridae	01	02	00
Order: Gymnophiona (caecilians)				
14.	Family: Chikilidae	01	04	03
15.	Family: Ichthyophidae	02	21	20
16.	Family: Indotyphlidae	02	14	14
	Total	69	447	329

7.2 Distribution of Amphibians in Different Biogeographic Zones and Biodiversity Hotspots of India

The distribution of amphibians in different biogeographic zones of India reveals that the Western Ghats has the highest species diversity 222 species with 198 endemics, followed by North-east India with 112 species of which 53 are endemic (Fig. 7.1). The Andaman and Nicobar Islands have high endemicity as 12 out of its 20 species are endemic to these islands (Venkataraman and Deoti 2015).

The distribution of amphibians in different biodiversity hotspots of India reveals that followed by the Western Ghats, the Indo-Burmese biodiversity hotspot has 127 species of which 59 are endemic, while the Himalayas has 89 species of which 27 are endemic (Fig. 7.2).

The number of species and genera of amphibians in different biogeographic zones and biodiversity hotspots of India along with the endemic status (Table 7.2).

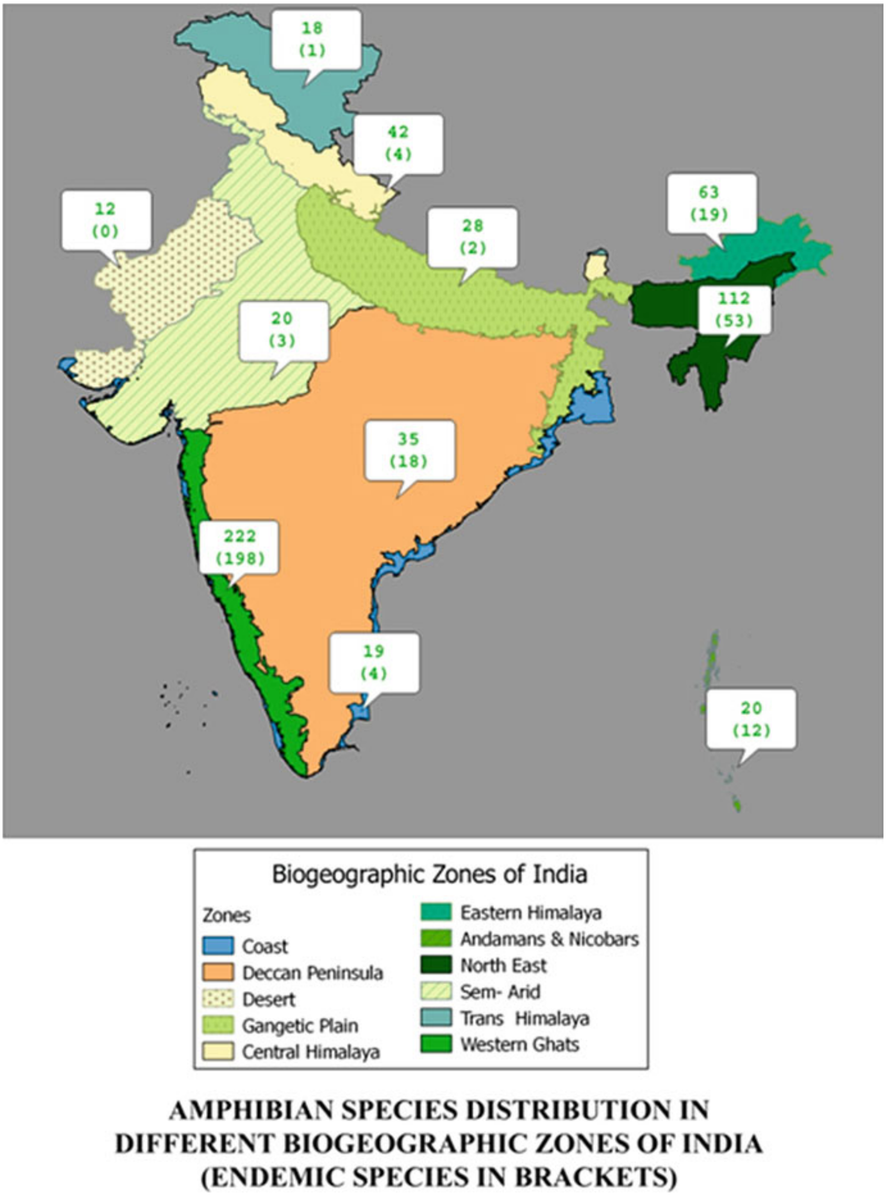

Fig. 7.1 Amphibian species distribution in different biogeographic zones of India. In each state, the number of endemic species is given in parenthesis

There are 3 species of crocodiles, 36 species of turtles, 313 species of lizards and 329 species of snakes known from India (Table 7.3). This total of 681 reptile species known from the country belongs to 163 genera and 28 families under 3 orders

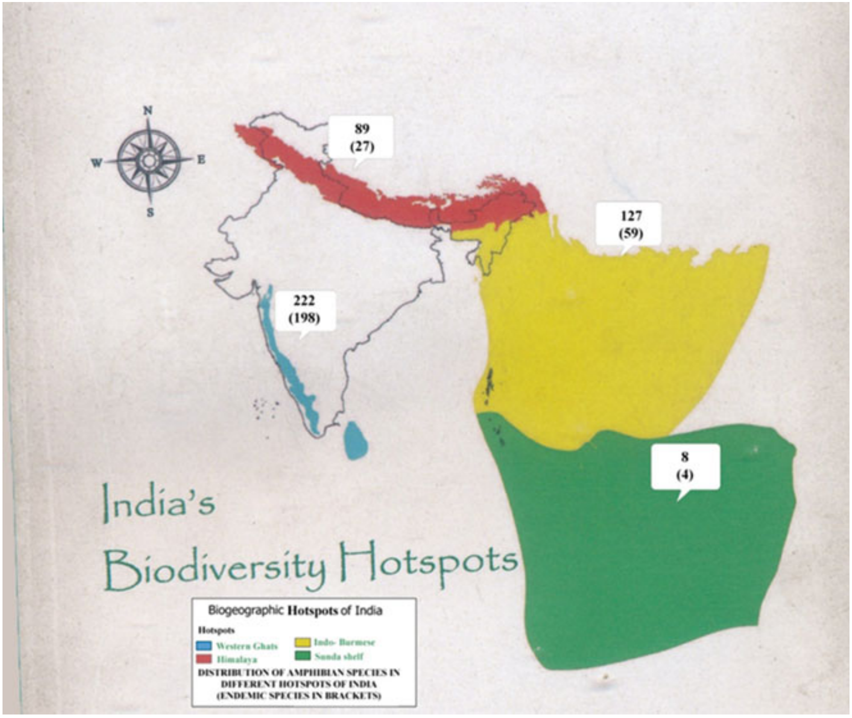

Fig. 7.2 Amphibian species distribution in different biodiversity hotspots of India. In each hotspot, the number of endemic species is given in parenthesis

(Boulenger 1890; Tikader and Sharma 1992; Whitaker and Captain 2004; Venugopal 2010; Das 1995, 1996, 2002, 2003, 2010, 2012; Uetz 2014; Purkayastha et al. 2015; Deuti et al. 2020). About 197 species of lizards are endemic (62.9%), while 117 species of snakes are endemic (35.5%). Overall, 318 out of 681 species of Indian reptiles are endemic (46.7%) (Table 7.3).

7.3 Distribution of Reptiles in Different Biogeographic Zones and Biodiversity Hotspots of India

The distribution of reptiles in different biogeographic zones of India reveals that the Western Ghats has maximum species diversity of 255 species with 162 endemics, followed by the Deccan Peninsula with 229 species and 95 endemics (Fig. 7.3). The Gangetic plains also has 185 species but with few (13) endemics. North-east India has 155 species but with only 9 endemics, understandably as most of these species are found in neighbouring countries too. The Andaman and Nicobar Islands have high endemicity as 29 of its 77 reptiles are endemic (Fig. 7.3).

Table 7.2 Total number of genera and species and number of endemic genera of amphibians in biogeographic zones and biodiversity hotspots of India

S. No.	Area/region	Total number of species	Total number of endemic species	Total number of genera	Total number of endemic genera
Biogeographic zones					
01.	Western Ghats	222	198	30	3
02.	Coasts	19	4	9	0
03.	Deccan peninsula	35	18	14	0
04.	Gangetic plains	28	2	13	0
05.	Semi-arid areas	20	3	11	0
06.	Desert	12	0	9	0
07.	Trans-Himalaya	18	1	9	0
08.	Central Himalaya	42	4	21	0
09.	Eastern Himalaya	63	19	25	1
10.	North-east	112	53	33	3
11.	Andaman and Nicobars	20	12	12	1
Biodiversity hotspots					
01.	Western Ghats	222	198	30	3
02.	Himalayas	89	27	36	3
03.	Indo-Burmese	127	59	33	3
04.	Sunda shelf	8	4	7	0

The distribution of reptiles in different biodiversity hotspots reveals that apart from the Western Ghats, high species diversity is prevalent in the Indo-Burmese biodiversity hotspot with 209 species although endemics are fewer (21 species). The Himalayas has 157 reptiles with few (12) endemics too (Fig. 7.).

The number of species and genera of reptiles in different biogeographic zones and different biodiversity hotspots of India along with the endemic species and genera in those areas (Table 7.4).

Among reptiles, the turtles in different biogeographic zones reveal that a maximum number of turtle species are found in the Gangetic plains, North-east India and Deccan Peninsula with the Deccan alone having three endemic species. The Western Ghats has nine turtle species with three endemics also. Besides, the semi-arid zone also has 11 species (Fig. 7.5).

Table 7.3 An overview of taxonomic diversity and endemic species of reptiles in India

S. No.	Order/sub-order/family	Number of genera	Number of species	Endemic species to India
Order: Crocodylia				
01.	Family: Gavialidae (gharials)	1	1	0
02.	Family: Crocodylidae (crocodiles)	1	2	0
Order: Chelonia				
03.	Family: Geoemydidae (hard-shelled turtles)	9	17	1
04.	Family: Trionychidae (soft-shelled turtles)	5	8	1
05.	Family: Testudinidae (tortoises)	3	6	2
06.	Family: Cheloniidae (sea turtles)	4	4	0
07.	Family: Dermochelidae (leatherback turtle)	1	1	0
Order: Squamata				
Sub-order: Sauria (lizards)				
08.	Family: Scincidae (skinks)	15	62	39
09.	Family: Agamidae (garden lizards)	20	69	34
10.	Family: Gekkonidae (wall lizards)	13	157	117
11.	Family: Lacertidae (snake-eyed lizards)	04	14	05
12.	Family: Varanidae (monitor lizards)	01	04	00
13.	Family: Chameleonidae (chameleons)	01	01	00
14.	Family: Eublepharidae (leopard geckos)	01	04	02
15.	Family: Anguidae (glass lizards)	01	01	00
16.	Family: Dibamidae (worm lizards)	01	01	00
Sub-order: Ophidia (snakes)				
17.	Family: Acrochordidae	01	01	00
18.	Family: Boidae	01	03	01
19.	Family: Pythonidae	02	03	00
20.	Family: Colubridae	40	179	48

(continued)

Table 7.3 (continued)

S. No.	Order/sub-order/family	Number of genera	Number of species	Endemic species to India
21.	Family: Elapidae	07	40	06
22.	Family: Homalopsidae	08	08	00
23.	Family: Leptotyphlopidae	01	01	00
24.	Family: Pareidae	01	04	00
25.	Family: Typhlopidae	04	18	04
26.	Family: Uropeltidae	07	42	40
27.	Family: Viperidae	09	29	10
28.	Family: Xenopeltidae	01	01	04
	Total	163	681	318

The distribution of turtles in different biodiversity hotspots reveals that the Indo-Burmese biodiversity hotspot has maximum number of turtle species (25) while the Himalayas has nine species (Fig. 7.6).

The distribution of lizard species in different biogeographic zones of India reveals that a maximum number of lizards are found in the Western Ghats, 127 species with 87 endemics. The Deccan Peninsula has 100 species with 57 endemics. The Andaman and Nicobar Islands have high lizard endemicity. Fourteen of 29 lizards here are endemic (Fig. 7.7).

The distribution of lizards in different biodiversity hotspots of India reveals that the Indo-Burmese biodiversity hotspot has 63 species with 11 endemics while the Western Ghats has 127 species with 87 endemics. Besides, the Himalayas has about 42 species with few (6 species) endemics. Compared to that, the Sunda Shelf has 6 out of its 15 species as endemics (Fig. 7.8).

The distribution of snake species in different biogeographic zones of India reveals that a maximum number of snakes are found in the Western Ghats, 134 species with 73 endemics. The Gangetic plains is the next most diverse with 126 species although only 6 are endemic (Fig. 7.9). The Deccan Peninsula has also high snake diversity with 108 species of which 35 are endemic. North-east India has also 92 snake species although only 3 are endemic as these species occur in neighbouring countries. Andaman and Nicobar Islands have 15 endemic snake species of the 43 found there (Fig. 7.9).

The distribution of snakes in different biodiversity hotspots reveals that apart from Western Ghats which has the highest snake diversity (134 species) and high endemicity (73 species), the Indo-Burmese biodiversity hotspot also has high snake diversity (121 species) but few endemics (10 species). The Himalayas also has 106 snake species but few endemics (6 species). Compared to these, the Andaman and Nicobar Islands have nine of its ten snakes as endemic to these islands (Fig. 7.10).

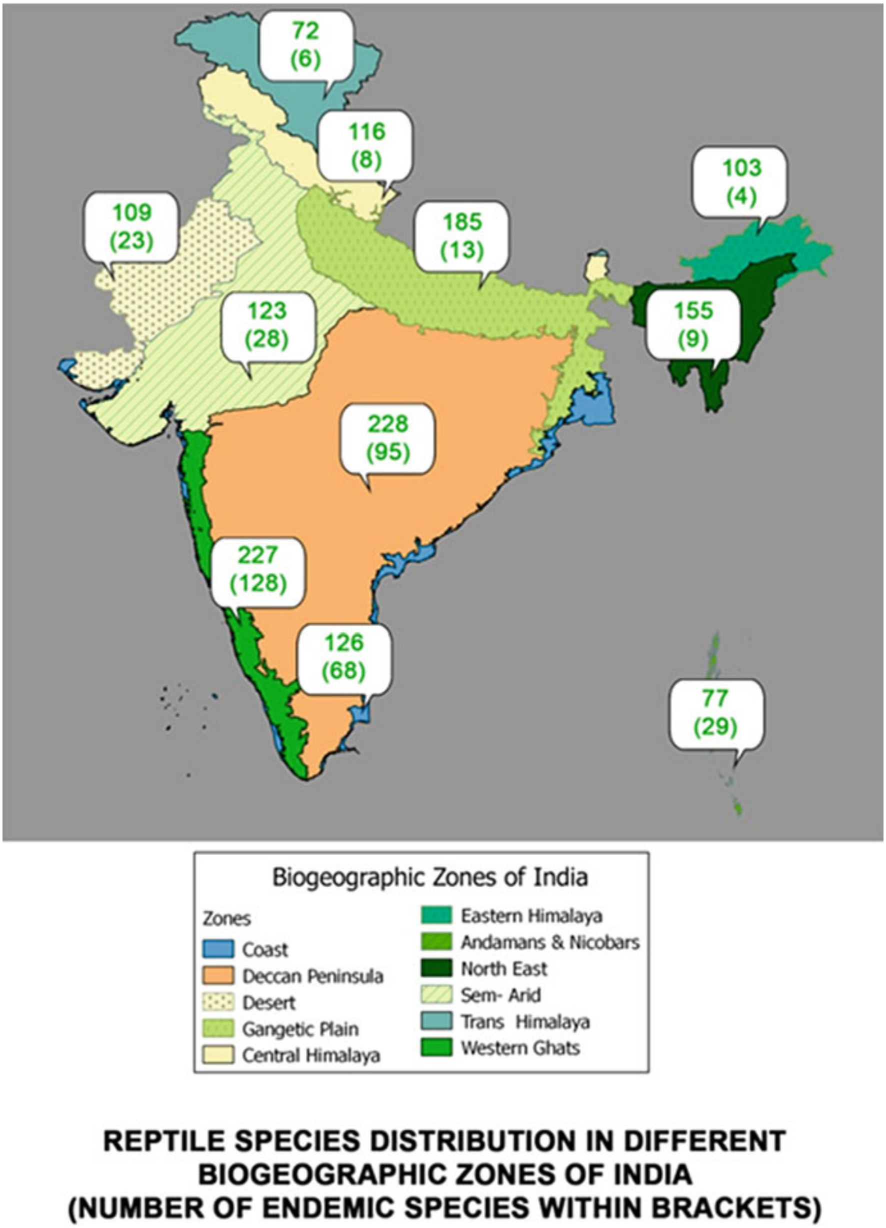

Fig. 7.3 Distribution of reptiles in different biogeographic zones of India. The number of endemic species is given in parenthesis

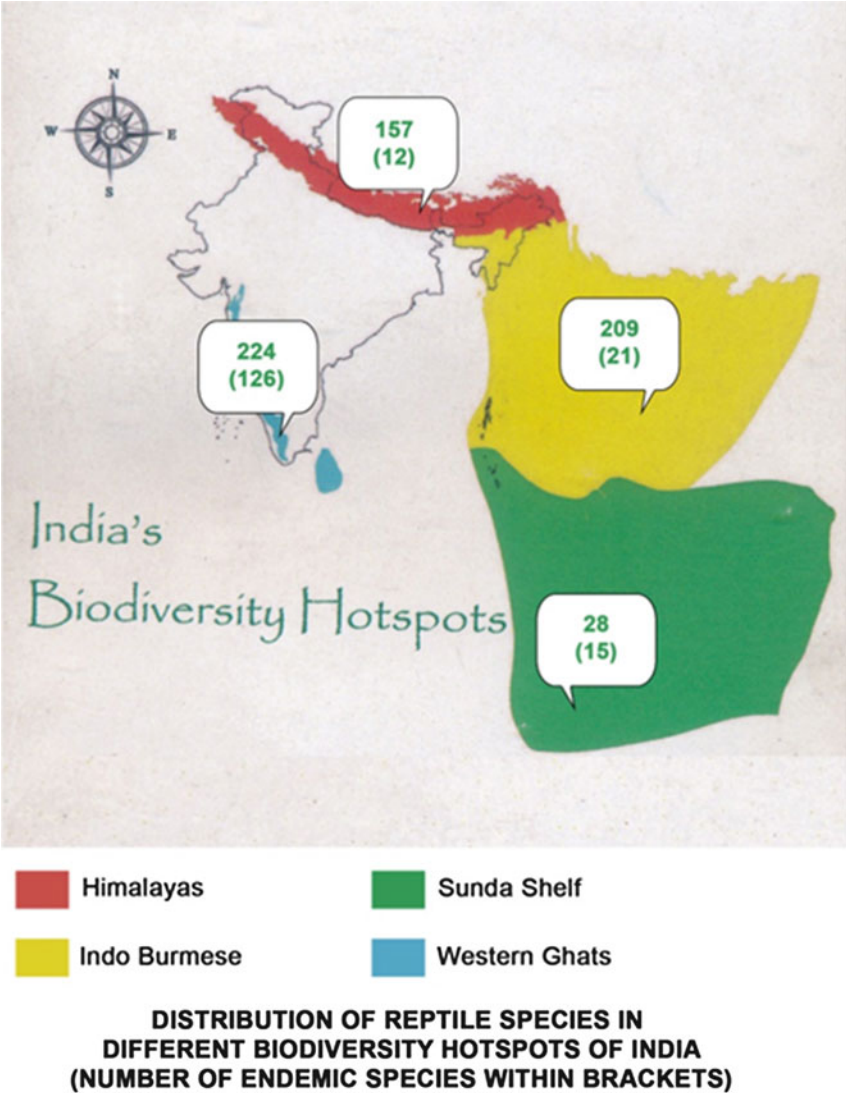

Fig. 7.4 Distribution of reptiles in different biodiversity of India. The number of endemic species is given in parenthesis

7.4 Herpetofauna of some Important Biogeographic Zones

7.4.1 The Himalayas

Amphibians: About 100 species are known from the Himalayas. Species of certain genera are unique to these mountains. Thirteen species of *Amolops* (family Ranidae)

Table 7.4 Total and number of endemic genera and species of amphibians in biogeographic zones and biodiversity hotspots of India

S. No.	Area/region	Total number of species	Total number of endemic species	Total number of genera	Total number of endemic genera
Biogeographic zones					
01.	Western Ghats	255	162	74	
02.	Coasts	156	68	41	18
03.	Deccan peninsula	228	95	83	35
04.	Gangetic plains	185	13	83	10
05.	Semi-arid areas	123	28	61	19
06.	Desert	109	23	61	14
07.	Trans-Himalaya	72	6	44	5
08.	Central Himalaya	116	8	57	6
09.	Eastern Himalaya	103	4	54	4
10.	North-east	155	9	72	6
11.	Andaman and Nicobar	77	29	50	22
Biodiversity hotspots					
01.	Western Ghats	255	162	74	
02.	Himalayas	157	12	69	10
03.	Indo-Burmese	209	21	87	22
04.	Sunda shelf	28	15	23	13

and 16 species of *Megophrys* (family Megophryidae) are mainly found along the hill streams of the Himalayas. The tadpoles of *Amolops* have ventral suckers and scrape algae from submerged rocks, while the tadpoles of *Megophrys* have funnel-shaped mouthparts and are filter-feeders in the streams. Eleven species of *Nanorana* (family Dicroglossidae) are found in the Himalayan Forest floors. Besides some four species of *Scutiger* (family Megophryidae) and four species of *Liurana* (family Ceratobatrachidae) are typical of the higher altitudes of the Himalayas as are two species of *Allopaa* and *Bufo teslatastii* (Ladakh toad) and two species of salamanders (*Tylototriton himalayanus* & *T. verrucosus*) are found in the Himalayas at mid-altitudes (Deuti and Hegde 2007), while very few (3–4) species of caecilians are known from the Himalayas so far.

Reptiles: About 200 species belonging to 85 genera and 20 families are known from the Himalayas. The Eastern Himalayas has the highest reptilian diversity with 108 species followed by the Central Himalayas with 102 species and the Western

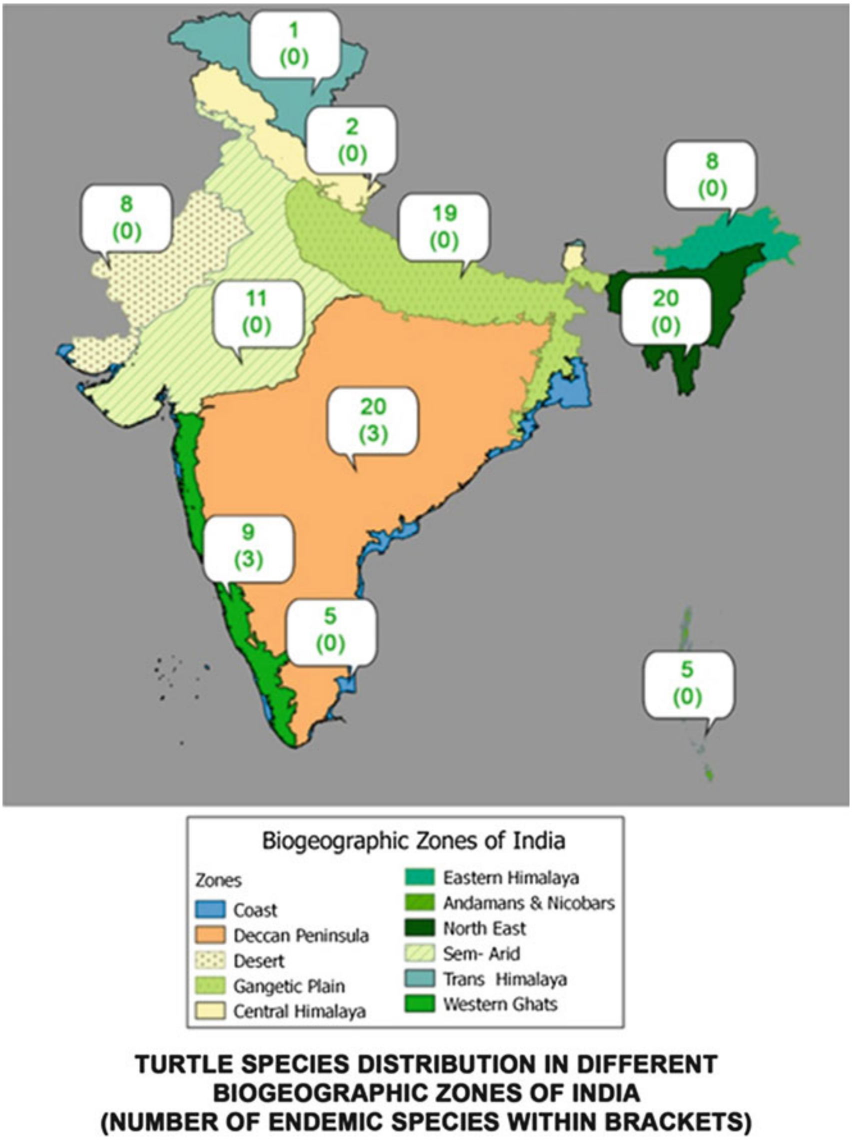

Fig. 7.5 Distribution of turtles in different biogeographic zones of India. The number of endemic species is given in parenthesis

Himalayas with 84 species. The Ladakh area has only 11 species and the Tibetan plateau even less, 6 species.

Endemic Reptiles: Only 13 species are endemic to the Himalayas (1 species of Agamidae, 1 species of Lacertidae, 4 species of Gekkonidae, 1 species of Typhlopidae and 6 species of Colubridae).

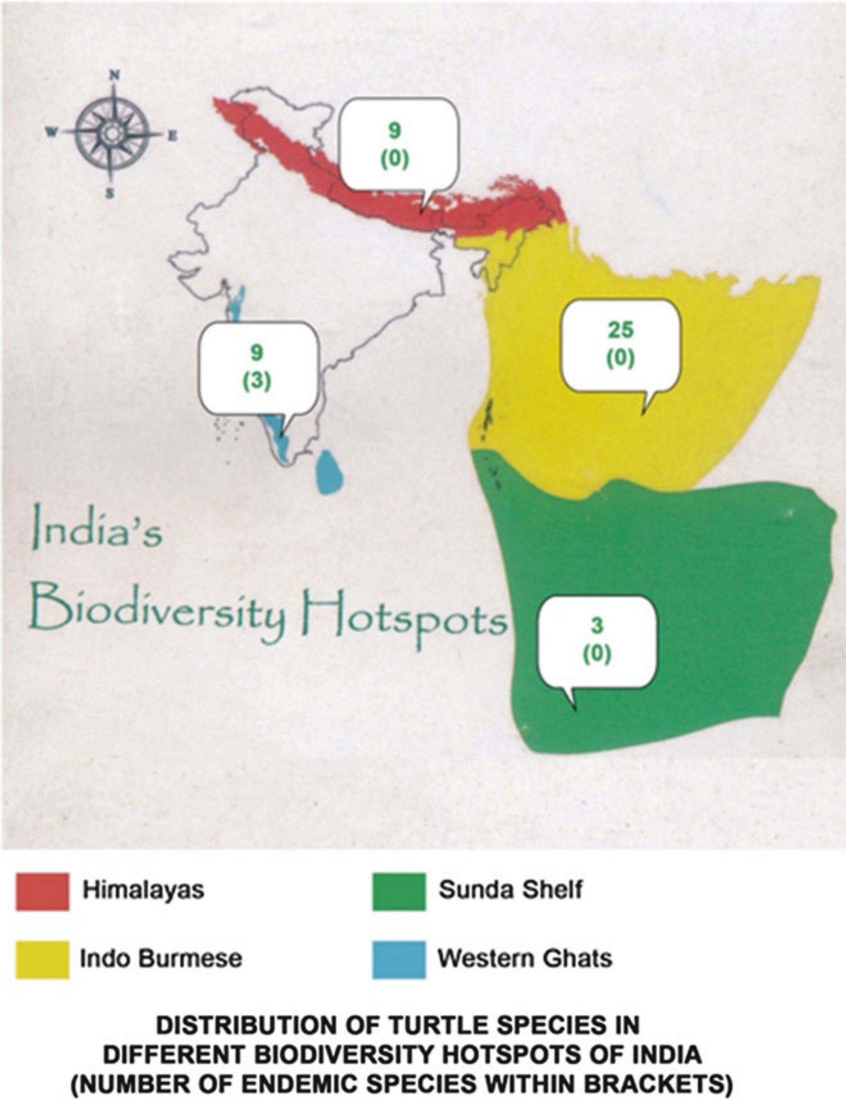

Fig. 7.6 Distribution of turtles in different biodiversity of India. The number of endemic species is given in parenthesis

Some Important Reptile Species.

Among crocodiles, the gharial (*Gavialis gangeticus*) and the mugger (*Crocodylus palustris*) are seen in the Himalayan foothills.

The important testudines are elongated tortoise (*Indotestudo elongata*), leaf turtle (*Cyclemys gemeli*), tricarinate hill turtle (*Melanochelys tricarinata*) and Assam roofed turtle (*Pangshura sylhetensis*).

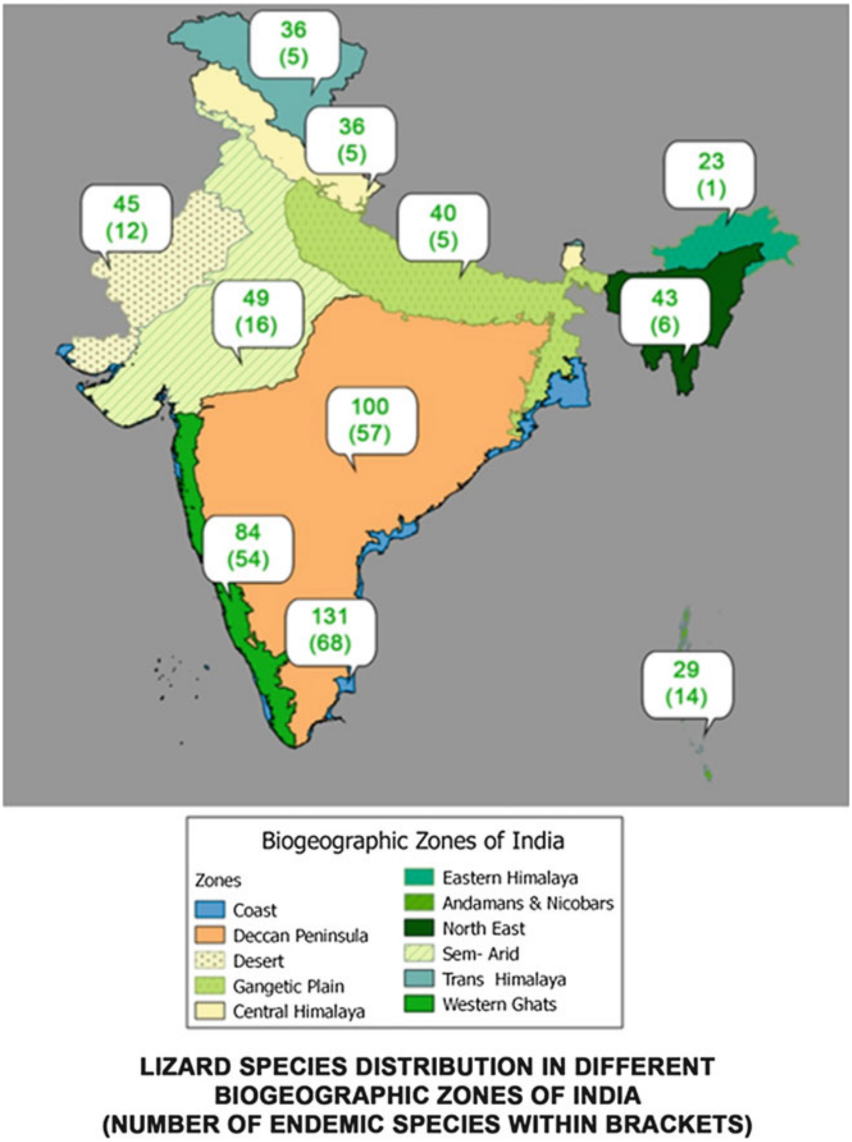

Fig. 7.7 Distribution of lizards in different biogeographic zones of India. The number of endemic species is given in parenthesis

Agamids lizards like *Laudakia* spp. (4 species), *Paralaudakia himalayana*, *Phrynocephalus theobaldi* (toad-headed agama), *Calotes jerdoni* (Jerdon's lizard), *Calotes mystaceus* (moustached lizard), *Draco maculatus* (spotted flying lizard), *Japalura* (6 species), *Calotes paulus*, *Pseudocalotes austeniana* and *Ptyctolaemus gularis* (blue-throated lizard).

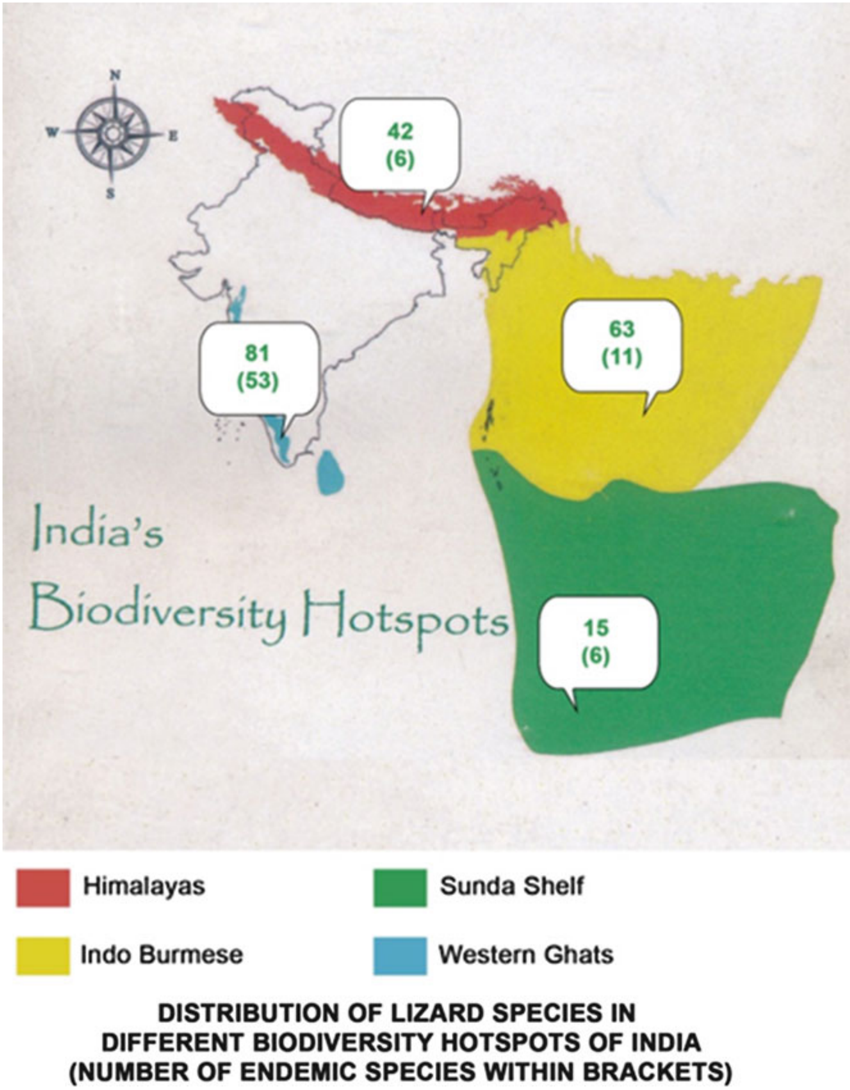

Fig. 7.8 Distribution of turtles in different biodiversity hotspots of India. The number of endemic species is given in parenthesis

Gekkonid lizards like *Altiphylax stoliczkai, Cyrtodactylus* (6 species), *Cyrtopodion* (3 species), *Hemidactylus* (6 species).

Lacertid lizards: 2 species of *Takydromus* (long-tailed lizards).

Skinks: *Asymblepharus* (4 species), *Sphenomorphus* (4 species), *Eutropis* (4 species), *Riopa* (2 species), *Eurylepis* (1 species).

Anguids like *Dopasia gracilis* (limbless lizard).

Monitor lizards like *Varanus bengalensis* and *V. flavescens.*

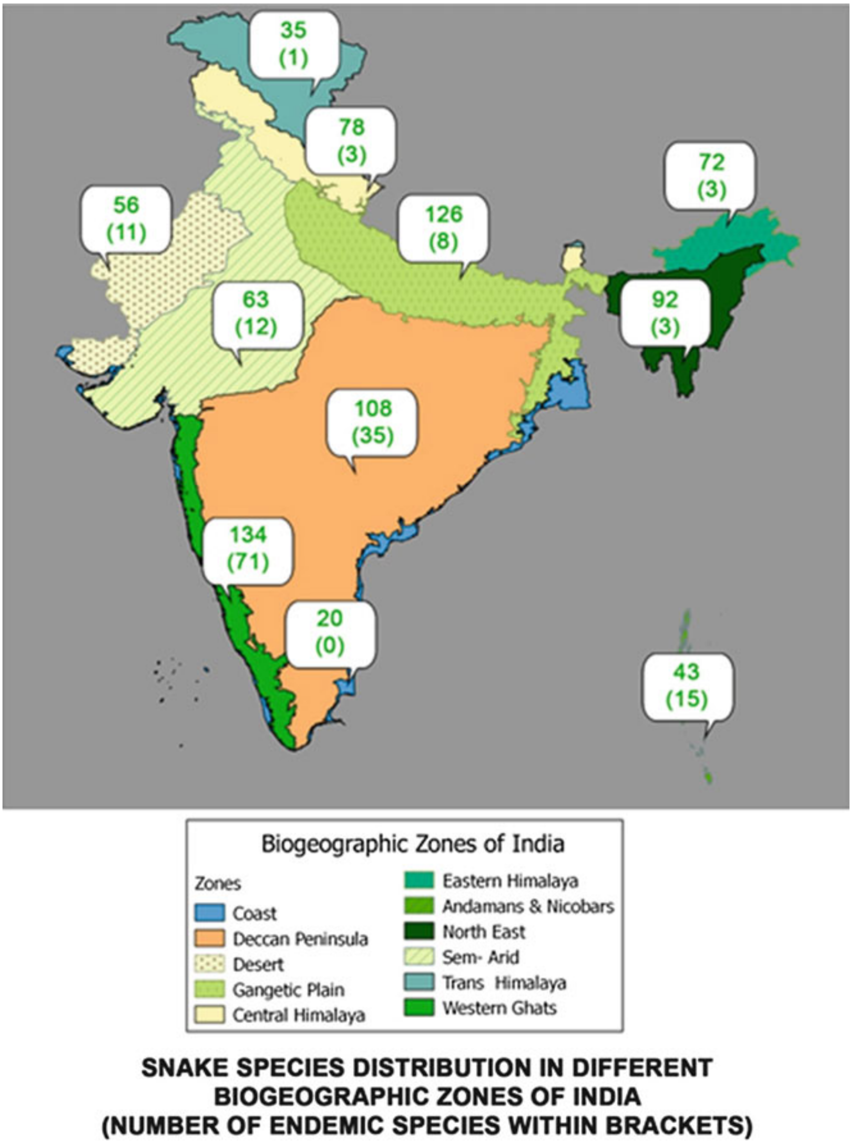

Fig. 7.9 Distribution of snakes in different biogeographic zones of India. The number of endemic species is given in parenthesis

Snakes like Indian rock python (*Python molurus*) and Burmese python (*Python bivittatus*).

Colubrid snakes like *Blythia* (2 spp.), *Smithophis* (3 spp.), *Ahaetulla* (2 spp.), *Boiga* (10 spp.), *Dendrelaphis* (4 spp.), *Liopeltis* (3 spp.), *Lycodon* (8 spp.), *Oligodon* (10 spp.), *Platyceps* (3 spp.), *Ptyas* (3 spp.), *Hebius* (4 spp.), *Herpetoreas*

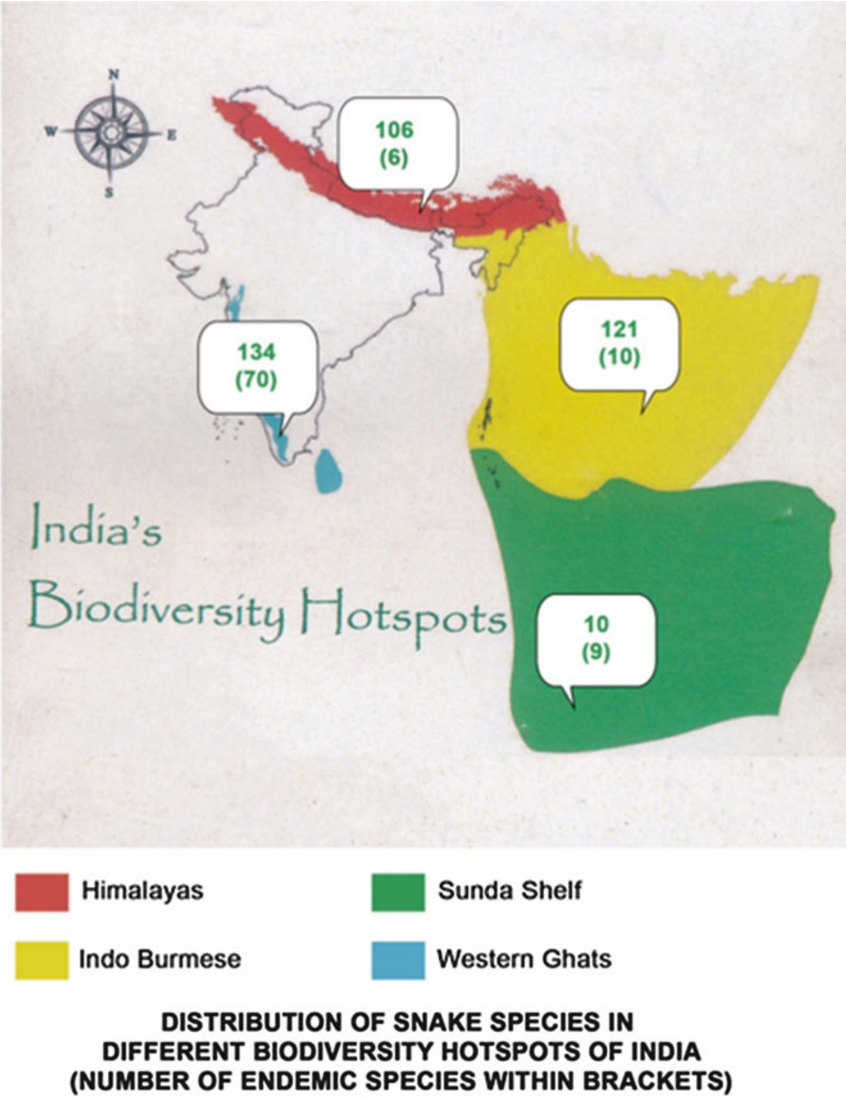

Fig. 7.10 Distribution of snakes in different biodiversity hotspots of India. The number of endemic species is given in parenthesis

(2 spp.), *Rhabdophis* (2 spp.), *Trachischium* (6 spp.), *Sibynophis* (2 spp.), *Psammophis* (3 spp.) and *Pareas* (2 spp.).

Elapid snakes like *Bungarus* (5 spp.), *Naja* (3 spp.) and *Ophiophagus hannah.*

Viperid snakes like *Gloydius* (1 sp.), *Ovophis monticola, Protobothrops* (4 spp.) and *Trimeresurus* (8 spp.).

7.4.2 Peninsular India

Amphibians: About 42 species are known including one newly described species of caecilian, *Gegeneophis orientalis*. Besides, several species like *Duttaphrynus* (4 spp.), *Microhyla* (4 spp.), *Uperodon* (10 spp.), *Euphlyctis* (2 spp.), *Hoplobatrachus* (2 spp.), *Fejervarya* (2 spp.), *Minervarya* (5 spp.), *Sphaerotheca* (3 spp.), *Hydrophylax* (2 spp.), *Clinotarsus* (1 spp.), *Indosylvirana* (4 spp.), *Polypedates* (1 spp.), *Raorchestes* (2 spp.) and *Pseudophilautus* (1 spp.) are found in this region (Murthy and Aengals 2008; Ganesh and Arumugam 2016).

Reptiles.

Some Important Reptile Species.

The star tortoise (*Geochelone elegans*) is important as it is highly exploited for the pet trade and is therefore protected in both Schedule I of the Indian Wildlife Protection Act and Appendix I of the Convention on International Trade in Endangered Species (CITES).

Gekkonid lizards of genus *Hemidactylus* (15 spp.) like granite rock gecko (*H. graniticolus*) from Karnataka/Tamil Nadu; (*H. vijayraghavani*) from Karnataka, reticulated gecko (*H. reticulatus*) from Tamil Nadu; many giant rock geckos (*H. sushilduttai, H. kangerensis, H. hemachandrai, H. yajurvedi*), from Andhra Pradesh, yellow-tailed geckos (*H. flavicaudus, H. xericolus*) from Telangana, Truetler's rock gecko (*H. treutleri*) from Telangana; Sankari rock gecko (*H. sankariensis*), Sirumalai rock gecko (*H. sirumalaiensis*) and Kolli rock gecko (*H. kolliensis*) from Tamil Nadu; and Rishi Valley rock gecko (*H. rishivalleyensis*) from Andhra Pradesh/Tamil Nadu.

Gekkonid lizards of genus *Cnemaspis* (25 spp.) like Horsley day gecko (*C. graniticola*), Rishi Valley day gecko (*C. rishivalleyensis*) from Andhra Pradesh; Adi's day gecko (*C. adii*), Mysore round-eyed Gecko (*C. mysoriensis*) and star-dust day gecko (*C. stellapulvis*) from Karnataka, Yelagiri day gecko (*C. yelagiriensis*), Yercaud day gecko (*C. yercaudensis*), Ota's day gecko (*C. otai*), Agarwal's day gecko (*C. agarwali*), Thackeray's day gecko (*C. thackerayi*), Shevaroy day gecko (*C. shevaroyensis*) from Tamil Nadu.

Gekkonid lizards of genus *Cyrtodactylus* like Srilekha's bent-toed gecko (*C. srilekhae*), Kollegal bent-toed gecko (*C. collegalensis*) both from Karnataka/ Tamil Nadu, Rishi Valley bent-toed gecko (*C. rishivalleyensis*) from Andhra Pradesh.

Gekkonid lizards of genus *Hemiphyllodactylus* (6 species) like *H. aurantiacus, H. jnana, H. kolliensis* from Tamil Nadu, and *H. arakuensis* from Andhra Pradesh/ Orissa, and *H. minimus* from Orissa (Dutta et al. 2009).

A unique and protected lizard species from this area is the golden gecko (*Calodactylodes aureus*) distributed in Tamil Nadu, Karnataka, Andhra Pradesh and Orissa.

Agamid lizards include the Southern green garden lizard (*Calotes calotes*), Roux's forest lizard (*Monilesaurus rouxii*), Southern flying lizard (*Draco dussumieri*), rock lizards (2 spp. of *Psammophilus*), 5 spp. of fan-throated lizards of the genus *Sitana*, viz. *S. ponticeriana, S. gokakensis, S. thondalu, S. visiri* and *S. marudhamneydhal* (Deepak et al. 2016) as well as 2 spp. of colourful fan-throated lizards *Sarada* (*S. superba, S. darwini*).

Skinks like Peninsular limbless skink (*Sepsophis punctatus*), Beddome's blue-tailed ground skink (*Kaestlea beddomei*), supple skinks of genus *Riopa* (5 spp.) and *Subdoluseps pruthi* and sun skinks of genus *Eutropis* including Nagarjunsagar skink (*E. nagarjunensis*), Beddome's skink (*E. beddomei*) and Bibron's skink (*E. bibronii*).

Lacertid lizards like *Ophisops jerdonii, O. beddomei, O. leschenaultii* and *O. minor*.

The Indian chameleon (*Chamaeleo zeylanicus*).

Snakes like Indian rock python (*Python molurus*), common sand boa (*Eryx conicus*), red sand boa (*Eryx johnii*).

Typhlopid blind snakes like *Grypotyphlops acutus* and *Indotyphlops braminus*.

Gerrhopilid snakes like *Gerrhopilus* sp. from Tamil Nadu and Andhra Pradesh.

Uropeltid or shield tail snakes like *Rhinophis goweri, Uropeltis dindigalensis*, *U. rajendrani* and *U. shortii* from Tamil Nadu and *Uropeltis ellioti* also from Karnataka, Andhra Pradesh, Orissa, Chhattisgarh and even Madhya Pradesh.

Indian sand snake (*Psammophis*) – Lamprophiidae from Andhra Pradesh, Telangana, Orissa and Karnataka.

Colubrid snakes like Bhola Nath's racer (*Platyceps bholanathi*), bridal snake (*Dryocalamus nympha*), reed snake (*Liopeltis calamaria*), black-headed snake (*Sibynophis subpunctatus*), collared cat snake (*Boiga nuchalis*), Forsten's cat snake (*B. forsteni*), yellow-green cat snake (*B. flaviviridis*), kukri snakes (*Oligodon taeniolatus, O. arnensis*), wolf snakes (*Lycodon aulicus, L. anamallensis, L. striatus, L. deccanensis, L. flavicollis*).

Elapid snakes like slender coral snake (*Calliophis melanurus*), Beddome's coral snake (*C. beddomei in* Tamil Nadu), common krait (*Bungarus caeruleus*), spectacled cobra (*Naja naja*) and king cobra (*Ophiophagus hannah*) in Andhra Pradesh/ Orissa.

Viperid snakes like Russell's viper (*Daboia russelii*), saw-scaled viper (*Echis carinatus*) and bamboo pit viper (*Trimeresurus gramineus*) in all the covering states and additionally Salazar pit viper (*T. salazar*) in Madhya Pradesh, Chhattisgarh and Orissa and spot-tailed pit viper (*T. erythrurus*) in Orissa/Andhra Pradesh.

7.4.3 Western Ghats

Amphibians: The Western Ghats are a treasure trove of amphibians, and some families like Nyctibatrachidae (night frogs: 36 species), Micrixalidae (dancing frogs: 24 species), Ranixalidae (Indian frogs: 17 species) and Nasikabatrachidae (pig-nosed frogs: 2 species) are endemic to this biodiversity hotspot (Chandramouli and Ganesh 2011). Besides, several species of rhacophorids (tree and bush frogs) are endemic to this region. About 26 species of caecilians (limbless amphibians) are endemic to the Western Ghats with some genera like *Uraeotyphlus, Gegeneophis* and *Indotyphlus* being found exclusively there.

Reptiles: Total of 255 reptile species including 127 lizards and 122 snakes (Jerdon 1870; Smith 1931, 1935; Murthy 1985, 1986, 1990; Ishwar et al. 2001; Sharma 2002; Bhupathy and Nixon 2011; Ganesh et al. 2013; Palot 2015; Pal et al. 2018). Among lizards, agamids (19 spp.), skinks (25 spp.) and geckos (75 spp.) and among snakes, colubrids (51 spp.), uropeltids (39 spp.), xenodermatids (4 spp.), gerrhophilids (3 spp.), elapids (9 spp.) and viperids (8 spp.).

Endemic Reptiles: Eighty-seven lizards and 73 snakes are endemic to the Western Ghats. Among lizards, 13 species of agamids, 17 species of skinks and 57 species of geckos are endemic. Among snakes, 19 species of colubrids, 38 species of uropeltids, 4 species of xenodermatids, 3 species of gerrhophilids, 2 species of elapids and 4 species of viperids are endemic. Among turtles, the Cochin forest cane turtle (*Vijayachelys silvatica*) and the Travancore tortoise (*Indotestudo travancorica*) are endemic (Bossuyt et al. 2004).

Some Important Reptile Species.

Apart from the Cochin forest cane turtle and Travancore tortoise, important skinks of the Western Ghats are 5 species of blue-tailed ground skinks (*Kaestlea* spp.), 4 species of Cat skinks (*Ristella* spp.), 2 species of tree skinks (*Dasia johnsinghi* and *Dasia subcaerulea*), Poona skink (*Eurylepis poonaensis*) and Ponmudi skink (*Eutropis clivicola*).

Important agamid lizards of the Western Ghats are four species of ring-necked lizards (*Monilesaurus*), one species of small-eared lizard (*Microauris*), two species of spiny-backed lizards (*Salea*), the Western Ghats flying lizard (*Draco dussumieri*), two species of fan-throated lizards (*Sitana*), three species of colourful fan-throated lizards (*Sarada*) and one species of kangaroo lizard (*Otocryptis beddomei*).

Important geckos of the Western Ghats include 32 species of day geckos (*Cnemaspis*), 7 species of *Dravidogecko,* 3 species of *Hemiphyllodactylus* and the golden gecko (*Calodactylodes*).

Colubrid snakes that are important are four species of vine snakes (*Ahaetulla*), *Proahaetulla antiqua,* seven species of cat snakes (*Boiga*), five species of bronze-back tree snakes (*Dendrelaphis*) and nine species of wolf snakes (*Lycodon*).

Important elapid snakes are six species of coral snakes (*Calliophis*) and king cobra (*Ophiophagus hannah*).

Three species of *Gerrhopilus* and four species of wood snakes (*Xylophis*) are also important.

Important shieldtails or uropeltids are *Melanophidium* (4 spp.), *Plectrurus* (3 spp.), *Platyplectrurus* (2 spp.), *Rhinophis* (4 spp.), *Teretrurus* (2 spp.) and *Uropeltis* (23 spp.).

Four species of pit vipers (*Hypnale hypnale*, *Trimeresurus malabaricus, T. macrolepis, T. strigatus*) and Hutton's pit viper (*Tropidolaemus huttoni*) are also important.

7.4.4 North-East India

Amphibians: About 135 species are found in north-east India (Ahmed et al. 2009; Pawar and Birand 2001). This includes some unique species like the Khasi hills rock toad (*Bufoides meghalayana*) and the Garo hills rock toad (*Bufoides kempi*), the Indian hylid frog (*Hyla annectans*), Assam painted frog (*Kaloula assamensis*), orange sticky frog (*Kalophrynus orangensis*), Manipur skittering frog (*Euphlyctis ghoshi*), Mawlindip frog (*Limnonectes mawlyndipi*), Mokokchung Mountain frog (*Nanorana mokokchungensis*), Assamese cascade frog (*Amolops assamensis*), point-nosed frog (*Clinotarsus alticola*), Bright frog (*Humerana humeralis*), Mawphlang Odorous frog (*Odorrana mawphlangensis*), Nagaland gliding frog (*Pterorana khare*), long-tongued frog (*Hylarana leptoglossa*), Annandale's tree frog (*Chirixalus simus*), Garo hills bush frog (*Raorchestes garo*), Namdapha bush frog (*Raorchestes namdaphaensis*), Shillong bush frog (*Raorchestes shillongensis*), twin-spotted tree frog (*Rhacophorus bipunctatus*), red webbed tree frog (*Rhacophorus rhodopus*) and large green tree frog (*Zhangixalus smaragdinus*). Caecilians like *Chikila* (4 spp.) and *Ichthyophis* (6 spp.) are also found in this region, the former genus being endemic.

Reptiles: About 180 species of reptiles inhabit north-east India. This includes about 54 species of lizards, 106 species of snakes, 22 species of testudines and 2 species of crocodiles (Pawar and Birand 2001; Purkayastha 2013). The recently described snake genus *Smithophis* is endemic to this subregion.

Some Important Reptile Species.

The mugger and gharial are the two crocodilian species found in north-east India. Among tortoises, Asian brown tortoise, elongated tortoise and impressed tortoise are important. Among turtles, black softshell turtle (*Nilssonia nigricans*) is endemic to north-east India. Other important species are Assam roofed turtle (*Pangshura tecta*), tricarinate hill turtle (*Melanochelys tricarinata*), Malayan box turtle (*Cuora amboinensis*), keeled box turtle (*Cuora mouhotii*), Indian leaf turtle (*Cyclemys gemeli*) and Indian eyed turtle (*Morenia petersi*).

Important agamid lizards of north-east India include blue-throated lizard (*Ptyctolaemus gularis*), spotted flying lizard (*Draco maculatus*), Blanford's flying lizard (*Draco blanfordii*), spiny-headed forest lizard (*Calotes emma*), Gray's forest lizard (*Calotes maria*) and moustached forest lizard (*Calotes mystaceus*).

Important geckos of north-east India are giant/gliding geckos (*Gekko gecko, Gekko lionotum*), many endemic bent-toed geckos (*Cyrtodactylus khasiensis*, *C. arunachalensis*, *C. himalayicus*, *C. gubernatoris*, *C. guwahatiensis*, *C. urbanus*, *C. tripuraensis*, *C. kazirangaensis*, *C. septentrionalis*, *C. jaintiaensis*, *C. montanus*, *C. nagalandensis*) and day geckos (*Cnemaspis assamensis*).

Important skinks of north-east India are Sikkimese rock skink (*Asymblepharus sikimmensis*), eyelid-less skink (*Sphenomorphus apalpebratus*) and north-east water skink (*Tropidophorus assamensis*).

Besides, three species of long-tailed lizards (*Takydromus* spp.) and the Asian glass lizard (*Dopasia gracilis*) are found in north-east India.

North-east India is home to over hundred species of snakes, notable among them are reticulated python (*Malayopython reticulatus*) which is of still doubtful distribution, iridescent snakes (*Blythia reticulata, B. hmuifang*), endemic keelbacks (*Hebius khasiense*, *Hebius parallelum, Hebius clerki, Hebius lacrima, Hebius venningi, Herpetoreas xenura, Herpetoreas pealii, Herpetoreas sieboldi*), Hubei keelback (*Rhabdophis nuchalis*), cat snakes (*Boiga gokool*, *B. siamensis*, *B. quincunciata*), vine snakes (*Ahaetulla prasina, A. fronticincta*), bronze-back-tree snakes (*Dendrelaphis subocularis, D. pictus, D. proarchos*), white-banded false wolf snake (*Dinodon septentrionalis*), wolf snakes (*Lycodon laoensis*, *L. jara, L. fasciatus, L. zawi*), kukri snakes (*Oligodon catenatus, O. cinereus, O. melanozonatus, O. erythrogaster, O. dorsalis, O. erythrorhachis, O. albocinctus, O. juglandifer, O. cyclurus, O. melaneus*), eastern trinket snake (*Orthriophis cantoris*), Assam snail eater (*Pareas monticola*), common mock viper (*Psammodynastes pulverulentus*), Indo-Chinese rat snake (*Ptyas korros*), Khasi hills trinket snake (*Rhadinophis frenatum*), Khasi earth snake (*Stoliczkia khasiensis*), Assam slender snake (*Trachischium monticola*), MacClelland's coral snake (*Sinomicrurus macclellandi*), endemic kraits (*Bungarus bungaroides, B. lividus, B. niger, B. fasciatus*), mountain pit viper (*Ovophis monticola*), Salazar's pit viper (*Trimeresurus salazar*), Pope's pit viper (*Trimeresurus popeiorum*), Jerdon's pit viper (*Protobothrops jerdonii*), Kaulback's pit viper (*Protobothrops kaulbacki*) and Medo pit viper (*Viridovipera medoensis*).

7.4.5 Andaman and Nicobar Islands

Amphibians: For small oceanic islands, the Andaman and Nicobar Islands harbour a remarkably rich amphibian fauna (Das 1999). Endemic species of amphibians of the islands include *Bijurana nicobariensis*, *Ingerana charlesdarwini*, *Minervarya nicobariensis*, *Minervarya andamanensis* and *Blythophryne beryet*. A few species such as *Limnonectes shompenorum* have subsequently been reported from Southeast Asia, while some like *Chalcorana chalconota* were first described from Southeast Asia and subsequently reported from these islands.

Reptiles: Reptiles are even more rich and diverse in the Bay Islands. Many species of globally charismatic reptiles such as the king cobra (*Ophiophagus hannah*), the saltwater crocodile (*Crocodylus porosus*), the water monitor (*Varanus salvator*) and the reticulated python (*Malayopython reticulatus*) occur in these islands.

Apart from these, a myriad of lesser-known range-restricted forms occur in these archipelagos. The following endemic lizards occur here: geckos such as *Gekko verreauxi*, *G. nicobarensis*, *Phelsuma andamanensis*, *Cyrtodactylus rubidus*, *C. adleri*, *C. nicobarensis*, *C. camortensis*, *Cnemaspis andersonii* and *Cnemaspis nicobariensis*; skinks such as *Dasia nicobarensis*, *Eutropis andamanensis*, *E. tytleri* and *E. dattaroyi;* and agamids such as *Coryphophylax subcristatus*, *Coryphophylax brevicauda*, *Bronchocela rubrigularis*, *B. danieli* and *Pseudocalotes andamanensis*.

Snakes are also diverse in the islands with many endemic species: elapids such as *Bungarus andamanensis* and *Naja sagittifera*; vipers like *Trimeresurus andersonii*, *T. labialis*, *T. mutabilis* and *T. davidi*; colubrids such as *Lycodon tiwarii*, *L. hypsirhinoides*, *Oligodon woodmasoni*, *Boiga andamanensis*, *B. wallachi* and *Dendrelaphis andamanensis*; and natricids like *Fowlea tytleri* and *Amphiesma nicobarensis*.

Chelonians such as *Cuora amboinensis* occur in the islands; the coasts are home to many marine turtles such as the common Green sea turtle (*Chelonia mydas*) and the endangered leather-back turtle (*Dermochelys coriacea*). Nesting beaches of such sea turtles add conservation value to these coastlines.

7.5 Threats

Herpetofauna is threatened due to habitat loss and fragmentation, expansion of agriculture, conversion of forest tracts into plantations like tea and coffee and human settlements. Mining and rock quarrying, tourism-related infrastructural developments, hunting for food and the pet trade are other major threats.

Besides factors like agriculture, residential and commercial development, other factors like transportation, invasive species, climate change and pollution are other threats to reptiles and amphibians. The various specific reasons for the population decline of herpetofauna in India are as follows.

7.5.1 Deforestation and Habitat Destruction

Deforestation in the different parts of the country has resulted in the destruction of forests right up to the remotest corners of the country to make way for roads and farms. This has led to either complete loss of forests or the fragmentation of the different types of forests. This has isolated the herpetofaunal populations and relegated them to smaller sub-populations that are no longer genetically viable. Deforestation has affected not only the population of canopy-dwelling primates and other forest-dwelling wild animals but also the forest-dwelling amphibians. In some places, the opening of the canopy has resulted in desiccation of the moist leaf litter which has severely affected the population of the litter-dwelling amphibians. With the rainforest canopy no longer providing shade to the small rain pools on the forest floor, the small frogs can no longer find their suitable breeding habitat. Certain forestry practices such as removal of the leaf litter are also causing herpetofaunal population decline (Davidar et al. 2007; Deepak and Vasudevan 2008). Many of these herpetofaunal species are so far known from only one small forest patch, i.e. they are point endemic, and with the destruction of these small forest patches, these small endemic herpetofauna are vanishing before scientists are discovering anything about their life and habits (Fig. 7.11).

Fig. 7.11 Paddy fields encroaching into forests – a case of habitat fragmentation

North-east India at one time had extensive tropical wet evergreen forests stretching over thousands of square miles. The human population was low consisting of ethnic tribes living in small hamlets in the valleys and adjoining hills. These tribes used to practice slash and burn (jhum) cultivation where in a piece of land all the trees were cut down, allowed to dry in the sun for a few days and then burnt so that the resulting ash would fertilize the mineral-deficient soil. Crops were raised on this cleared patch of land until it no longer gave a good yield. Then the patch was abandoned, and a new stretch of forest was cleared and burnt. The formerly cultivated patch could stand fallow for 10–15 years for the trees to regenerate. After this, patch is cleared, burnt and cultivated again. This is called a jhum cycle. But with the increase of human population, this jhum cycle was tremendously shortened to only 3–4 years and any formerly cultivated patch now hardly gets time to regenerate. In some places, the excessive clearing of undergrowth (understory vegetation) for housing purposes and landscape gardening has resulted in a decrease in the presence of the leaf-litter dwelling herpetofauna (Fig. 7.12).

Increase in agriculture is one of the greatest threats to the Indian herpetofauna. The increase of farming involving the conversion of forest lands into commercial plantations such as tea, coffee and cardamom plantations is impacting most of the species. For example, the king cobra is severely impacted by logging and the ever-increasing expansion of agricultural lands into pristine forest habitats leading to increasing man-snake conflicts.

Residential and commercial development due to tourism-related infrastructural activities are also threatening many reptiles. An increasing trend of tourism in the Himalayas has been observed in recent years.

Logging, harvesting and hunting are other threats to the reptiles. The king cobra (*Ophiophagus hannah*) is affected due to logging, man-snake conflict due to deforestation and fuelwood collection. It is also affected by hunting for skin, meat and traditional Chinese medicine. Some skinks of the Western Ghats are endemic and are highly impacted due to expansion of human settlements, fuelwood and fodder

Fig. 7.12 Jhum (slash and burn) cultivation – the curse of North-east India

collection, livestock grazing and conversion of forest tracts into commercial tea plantations.

7.5.2 Damming of Rivers

India has several rivers and rivulets that debouch from the hills into the vast plains, and these become turbulent during the monsoons. Engineers use the potential of these rivers to tap hydroelectricity by damming them. As a result, the forests downstream have often been severely affected and with them the many small living creatures. Besides the construction of innumerable small check dams over the hill streams has resulted in the drying of these streams, thus affecting the stream-dwelling amphibians and reptiles.

7.5.3 Overfishing and Pollution

Moreover, overfishing in these hill streams, often by using poisons and electric charges from portable generators to shock the fish, has decimated the meagre population of hill stream amphibians. With the increase in human population, the domestic and agricultural sewage generated has polluted the hill streams, rivers and many wetlands leading to a further decrease in the population of fishes and amphibians.

7.5.4 Mining

Mining has also become a widespread threat to reptiles. *Hemidactylus albofasciatus* which has a preference for rocky habitat in the Malvan plateau of Sindhudurg and Ratnagiri districts of Maharashtra is threatened due to rock cutting and stone quarrying for construction purposes and livestock grazing. *Otocryptis beddomii* is also threatened by frequent forest fires that are causing a decline in the quality and extent of the habitat of this species (Fig. 7.13).

7.5.5 Pollution

Pollution is another major cause of the decline of the herpetofauna. The most common sources of pollution are sedimentation due to agriculture, urban runoff, detergents and domestic sewage. Industrial effluents extracted from mining and heavy industries such as iron ore, paper and textile mills are other sources of pollution. Runoff and sedimentation have increased significantly due to the increase of deforestation in the last three decades coupled with unsustainable land-use practices and heavy monsoons. Uropeltids and caecilians are impacted due to excessive use of pesticides and herbicides in the commercial plantations, thereby declining the extent and quality of their habitat.

7.5.6 Pesticides and Fungicides

Many scientists believe that increasing the use of pesticides and fungicides may be responsible for frog deaths. The spraying of pesticides not only poisons frogs

Fig. 7.13 Rock cutting for mining

directly, but also wipes out their food supply. Amphibians are susceptible to at least 211 different pesticides. Organo-phosphate insecticides, like malathion, are known to disturb the frog's development, distorting the growth of their limbs at the egg and tadpole stages. Frog deformities such as multiple or missing limbs and body abnormalities because of unchecked use of chemicals have already been reported from many areas. Amphibians are highly vulnerable to toxins because they have thin permeable skin that readily absorbs contaminants and their eggs lack protective shells and are highly permeable as well. Pollution by heavy metals, pesticides, aromatic hydrocarbons and radioactive waste is frequently invoked as a cause for local declines. In some heavily industrialized areas, pollution is so intense that it is a wonder that there are any herpetofauna left.

7.5.7 Global Trade and Capture of Frogs

Uncontrolled international trade in amphibians is also threatening several species. The Convention on International Trade in Endangered Species (CITES) or the Washington Convention has already banned trade in two amphibian species – Indian bull frog (*Hoplobatrachus tigerinus*) and green pond frog (*Euphlyctis hexadactylus*). As many as 30 frogs are killed to make a kilogram of frog legs. India exported as much as 4000 tonnes of frog legs a year in the mid-1980s. During the heydays of frog-leg export, India used to export to many western countries like the USA, France, Belgium, Holland and what was then called West Germany. India started exporting frog legs in 1957, and by the mid-1980s it had become the biggest exporter. Prior to its ban in India, exports grew substantially over the last two decades, because of increased demand from the west and due to better freezing techniques and improved transport facilities. The volume exported in 1983 was seven times that of 1963. After the ban in India, Bangladesh and Indonesia have become major exporters of frog legs. But not even a total ban can prevent the killings; illegal export continues to thrive in all three countries. Frogs are particularly important for a country such as India, where the agricultural sector plays a vital role in the economy. They devour pests that pose a threat to crops and prevent the spread of vector-borne diseases like malaria because they consume parasites responsible for the disease. An adult frog devours its own weight of insects daily. Thus, if its population goes down, the insect population goes up. The decimation of frogs means increasing the use of pesticides which poses serious health hazards to all living organisms. According to experts at the Bombay Natural History Society, in many parts of western Maharashtra, crops have been badly hit by proliferating insects because of the large-scale slaughter of frogs. The Zoological Survey of India has also reported an increase in malaria in rural areas of West Bengal where 50% of frogs destined for export were captured.

7.5.8 Climate Change and Global Warming

The exact effects of climate change and global warming on the Indian herpetofauna are not known, or they are affected by any specific disease. The stresses of a changing climate could make amphibians more susceptible to infection. A change in the moisture regime or a change in water temperature might weaken amphibian immune systems. Warmer water might also affect a pathogen's virulence, or its capacity to move from one animal to another. Warmer air might increase the range of insects that carry it.

7.5.9 Acidification

Another anthropogenic disturbance that is suspected to have a negative effect on amphibian populations is the acidification of water bodies. In industrialized nations, this is happening because of increasing sulphur dioxide (SO_2) and nitrogen dioxide (NO_2) emissions. SO_2 (in the presence of sunlight) and NO_2 react with water vapour to form sulphuric and nitric acids. The rainwater contaminated with these acids affects flora and fauna both on land and water adversely.

7.5.10 UV Radiation

UV-B radiation from the sun has been reaching the Earth's surface during the spawning season. This is because of the destruction and thinning of the protective ozone layer in the atmosphere due to the use of chlorofluorocarbons (CFCs) and other human-manufactured chemicals. UV light can damage DNA and kill cells. UV radiation affects amphibian eggs in shallow lakes and ponds which either fail to hatch or produce deformed tadpoles. It is likely that increased UV levels are injuring other amphibians, particularly those at higher altitudes where the ozone layer tends to be weaker. Amphibians at higher elevations could be especially susceptible, since the higher you go, the less atmosphere there is to filter out the ultraviolet radiation.

7.6 Conservation

The majority of the species do not have any species-specific or habitat conservation strategies. Effective management of the areas where these species occur is needed for their conservation. Research on their ecology, biology (life history), population trends and habitat requirements is required to understand them and formulate conservation action plans for the conservation of the species and their habitats.

Reptilian species that are accorded protection by including them under various schedules of the Indian Wildlife Protection Act include *Gavialis gangeticus, Crocodylus porosus, Crocodylus palustris, Geochelone elegans, Boiga westermanni, Varanus bengalensis, Varanus salvator, Varanus flavescens* and *Varanus griseus* under Schedule I part II. *Ophiophagus hannah, Naja naja, Daboia russelii, Fowlea piscator, Ptyas mucosus, Atretium schistosum* and *Tylototriton himalayanus* are included under Schedule II part II. All other snakes belonging to the families Boidae, Colubridae, Elapidae, Typhlopidae, Uropeltidae and Viperidae are included under Schedule V of the Act. Although these species are accorded protection (by declaring protected areas like National Parks and Wildlife Sanctuaries and preventing illegal wildlife trade by various enforcement agencies like Forest, Police and Customs departments), various superstitious beliefs, man-animal conflicts due to human encroachment into forest lands for the expansion of agriculture and human settlements and hunting for food and subsistence, for skin and traditional medicine and for the pet trade are taking a heavy toll on many of the herpetofaunal species. Therefore, conservation awareness education programs about reptiles and amphibians and the ecosystem services they provide are essential to conserving the species and their habitats.

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Chapter 8
Status, Issues, and Challenges of Biodiversity: Wild Animals

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8.1 National Synthesis on Faunal Diversity and Conservation

India, known for its rich heritage of biological diversity, has so far documented nearly 102,616 species of animals (Chandra et al. 2020) and 49,441 species of plants in its 10 bio-geographic regions (BSI 2018). The country is recognized as one of the eight Vavilovian centers of origin and diversity of crop plants, having over 300 wild relatives and close rallies of cultivated plants. India has an immense repository of traditional knowledge (TK) associated with natural resources. The country is placed among the top ten natural resource-rich nations and shows a high level of endemism. Further, India is one of the 17 mega biodiversity countries of the world and one of the 4 in Asia encompassing more than 7% of the world's species diversity. The varied edaphic, climatic, and topographic variability has resulted in a diversity of ecosystems covering forests, wetlands, deserts, coastal and marine ecosystems, and grasslands. India also harbours four global biodiversity hot spots (Eastern Himalaya, Indo-Burma, Western Ghats and Islands of Sri Lanka, and Sundarbans). As per IUCN Red List (2020–2022), India harbours 1134 globally threatened species, out of which 703 species are of animals and 434 species of plants and fungi (IUCN 2020–2022). Of the total threatened species distributed in India, 92 species were classified as Critically Endangered, 219 as Endangered, and 389 species as Vulnerable (IUCN 2020–2022). The varied ecosystems of the country possess a high level of endemism, with 28.2% in plants and 28.26% in animals (BSI 2018; Chandra et al. 2020).

The forests of India are represented by 16 major forest types and 251 subtypes; at present, the total forest and tree cover of the country constitutes 21.67% (712,249 sq. km) of the total geographical area of the country out of which 3.03% is classified

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as very dense forest, 9.39% as moderately dense forest, and 9.26% as open forest (ISFR 2019). However, the National Forest Policy (NFP), 1988, aims at maintaining a minimum of 33% of the country's total geographical area under forest and tree cover. Against the prevailing global trend of decreasing forest cover, India, by and large, has been successful in stabilizing its area under forests over the years. However, the trends in dense forest cover type indicate a decrease in the area of forest with a dense canopy. In India, the varied active interactions between physical and biological components resulted in a variety of ecosystems that are spread over the different bio-geographic zones of India. The various ecosystems in India are usually represented as major natural habitats (forests, grasslands, deserts, wetlands [includes estuaries, mangroves, coral reefs, and marine); mountain ranges (Trans-Himalayas, North-West Himalayans, Eastern Himalayas including North-East hill states of India); Western and Eastern Ghats; and Deccan Peninsula.

The great variety of environments found in the mountain has created diverse types of ecosystems that are rich in species and genetic diversity. As a result, the mountain region of India, which includes the Himalayas and the Western Ghats, is one of the richest zones of biological diversity in the world. Globally, there has been a realization that the maintenance of biodiversity is vital for the well-being of humanity at present and for future generations. Biological diversity supports the functioning of ecosystems, which provides a large number of ecological services on which humanity depends, including provisioning, regulating, and supporting. The demand for such services is expected to grow up to fulfill the needs of the increasing human population and the expanding global economy, which is expected to reach nine billion by 2050 (Krishnan et al. 2012).

8.2 Ecosystem Diversity in India

8.2.1 Mountain Ecosystem (Himalayas, Western Ghats)

The mountain ecosystems of India have also been listed among the global biodiversity hot spots, viz., the Eastern Himalaya and the Western Ghats considering the high level of endemism and species richness. These mountain ecosystems are home to substantial populations of endemic flora (32% to 40%) and fauna (50%) of the total faunal diversity of India. The mountain ecosystem also holds some of the most important populations of species, which are classified as critically endangered and endangered, which includes species such as Hangul (*Cervus hanglu hanglu*), snow leopard, red panda, etc. The Western Ghats forest area is one of the best examples of non-equatorial tropical forests in the world. The wide array of climatic isotherm and topographic conditions of the Himalayan region provides a habitat for about 30,000 animal species (Chandra et al. 2019a). The vertebrate diversity in Indian Himalayan Region (IHR) is surplus and considered home to about 1814 vertebrate species which accounts for about 27.6% of the total diversity of vertebrates in India. Out of which, 126 species are classified as threatened under different threat categories

(CR, EN, and VU). Moreover, the mountain ecosystem is home to some of the largest rivers in India, which are the lifelines of millions of people living in the plains of the Indian subcontinent. These rivers provide valuable ecosystem services in the form of soil retention, climate regulation, and carbon sequestration apart from water to the region. The multi-ethnic composition within the mountain ecosystems makes it a distinct microcosm of biodiversity. However, in the present scenario in these mountain ecosystems, the rapid economic growth and limited integration of environmental concerns into development planning are leading to land-use change and biodiversity loss. The major threats to the biodiversity in the mountains include an expansion of crop areas into forests and the non-forest lands (pastures, etc.); repeated forest fire incidences and the construction of a large number of dams and reservoirs, quarrying and mining, presence of forest-based industries for raw material, inappropriate tourist activities, and the conversion of forest lands to plantation crops such as coffee, rubber, areca, etc. Unsustainable land-use practices, mass tourism, and over-subsistence dependence on forests and other areas are major challenges to biodiversity conservation.

8.2.2 Dryland

The dryland ecosystem covers about 41% of the earth's surface and is home to more than two billion people, and in India, drylands account for about 228.3 million hectares (NBSS & LUP 2010). These drylands are represented by hot arid (North-Western India) and cold arid zones (Jammu and Kashmir, Himachal Pradesh, Sikkim, Arunachal Pradesh). The dryland ecosystem is a fragile and vulnerable ecosystem due to strong emerging forces of environmental degradation. These degradation drivers include urbanization, monocultures, industrialization, mining, and poverty-induced overexploitation of natural resources. About 82.64 Mha of Indian drylands are classified as desertified lands as per the latest assessment (SAC 2016). These drylands support highly resilient species adapted to the seasonal pattern of rainfall and recurrent droughts that prevail in these ecosystems.

However, dryland biodiversity has prominent characteristics that are often overlooked. These include heterogeneity, a remarkable diversity of microorganisms, the presence of wild relatives of globally important domesticated species, and traditionally adopted land-use systems. Although drylands do not support a large number of species in comparison to temperate or humid regions because of extreme climatic conditions, these lands are best known because intra-specific diversity is probably much high in drylands than in forest ecosystems. The drylands are home to a relatively large number of endemic species of plants and animals uniquely adapted to the extreme climatic umbrella. The drylands are further classified as hot and cold drylands. The hot dryland habitat includes oasis, groves, ranns, saline depressions, open plains, and grasslands which are famous for many unique species of global conservation concern. These are blackbuck (*Antilope cervicapra*), Indian wild ass (*Equus hemionus khur)*, chinkara (*Gazella bennettii*), caracal (*Caracal caracal*), Deccan wolf (*Canis lupus pallipes*), and desert fox (*Vulpes vulpes pusilla)*. The drylands are home to some of India's most magnificent grasslands and sanctuary for a charismatic bird, the great Indian bustard (GIB, *Choriotis nigriceps*), and coastal biodiversity. A migration flyway used by cranes (*Grus grus*, *Anthropoides virgo*) and flamingos (*Phoenicopterus* species) crosses this region. Many rare species of reptiles are reported to be present including the lesser-known lizards such as alpine Punjab skink (*Eumeces taeniolatus*), dwarf gecko (*Tropiocolotes persicus euphorbiacola*), Persian gecko (*Hemidactylus persicus*), desert monitor (*Varanus griseus*), and warty rock gecko (*Cyrtodactylus kachhensis*), and the most common species of snakes were long-nosed worm snake (*Leptotyphlops macrorhynchus*), Sind longnose sand snake (*Lytorhynchus paradoxus*), and saw-scaled viper (*Echis carinatus sochureki*).

Whereas the cold drylands in India are represented by the Trans-Himalayan zone of India with severe to moderate levels of arid conditions, in the Trans-Himalayan zone, the temperature drops to −50 °C during winter, falling under rain shadow zones with enormous natural resources, possessing endemism and highly specialized biological elements and diversity of indigenous socio-cultural systems. The vegetation is cold deserts comprised of primarily alpine mesophytes and is home to many rare and endangered faunal species such as snow leopard (*Uncia uncia)*, Himalayan brown bear (*Ursus arctos isabellinus*), Tibetan wolf (*Canis lupus chanco*), Tibetan argali (*Ovis ammon hodgsoni*), Ladakh urial (*Ovis orientalis vignei*), Tibetan antelope (*Pantholops hodgsonii)*, wild dog (*Cuon alpinus*), and Tibetan wild ass (*Equus kiang*). The avifauna of the cold deserts is represented by nearly 250 species, which includes some restricted-range species such as black necked crane (*Grus nigricollis*), which breeds in the higher reaches of Ladakh. The other important birds of cold deserts are golden eagle (*Aquila chrysaetos*), Tibetan snowcock (*Tetraogallus tibetanus*), Tibetan partridge (*Perdix hodgsoniae*), bar-headed geese (*Anser indicus*), brown-headed gull (*Larus brunnicephalus*), mallard (*Anas platyrhynchos*), common pochard (*Aythya ferina*), common redshank (*Tringa totanus*), red-billed chough (*Pyrrhocorax pyrrhocorax*), and horned lark (*Eremophila alpestris*).

8.2.3 Wetlands Ecosystem

India is home to a range of wetland ecosystems from high-altitude cold desert wetlands to hot and humid wetlands in coastal zones which provide habitat to a wide range of animals and plants. These wetlands areas are distributed in different geographical regions ranging from the Himalayas to the Deccan plateau. As per the National Wetland Inventory (2011), India has about 201,503 wetlands of which 188,470 are inland and 13,033 are coastal wetlands. Additionally, about 555,557 wetlands of size <2.25 ha have also been mapped accounting for about 15.26 Mha area (4.63% of the total geographic area of India). These wetlands are classified into different categories based on their origin, vegetation, nutrient status, and thermal characteristics. The wetlands are known to have unique ecological features important for biodiversity and human well-being (Prasad et al. 2002). Presently 115 wetlands have been identified by the ministry, which requires urgent conservation and management intervention under the National Wetland Conservation Plan (NWCP). Out of which 26 wetlands are of international importance covered under Ramsar Convention, 1971. The wetland ecosystem harbours a good amount of floral as well as faunal diversity and plays a critical role in sustaining several migratory species of birds. About 1200 species of migratory birds are reported to use these wetlands in various stages of their life history (Agarwal 2011). A unique wetland such as Loktak Lake in Manipur is famous for floating mats of vegetation commonly called as *phumdi*, which is the only refuge for the endangered deer species sangai (Manipur brow-antlered deer) (Gray et al. 2015).

The wetlands of India are threatened because of several factors, which include human encroachment, an increase in population in the catchment area, and urbanization. The other major threats to wetlands are unsustainable exploitation of resources; conversion of wetlands for paddy cropping; removal of vegetation in the catchment area; unrestricted dumping of sewage, solid waste, and toxic chemical; salinization; etc. These factors are leading to the degradation of the quality and quantity of wetlands. Moreover, it is suggested that the inland wetlands in dryland are also likely to be impacted because of alternation in the hydrological regime and climatic aberration (Patel et al. 2009).

8.2.4 Marine Ecosystem

The marine ecosystem of India accounts for about 29% of the global ocean area, 13% of the marine organic carbon stocks, 10% of the mangroves, and 246 estuaries (Vanketraman et al. 2015). The marine ecosystem is represented by mangroves, lagoons, coral reefs, salt marshes, backwaters, rocky coasts, and sandy stretches, which possess a tremendous amount of faunal diversity because of unique biotic and abiotic characteristics. These marine ecosystems are spatially distributed on both the coasts (East and West) of India. However, the east and west coasts have significant dissimilarities in terms of exposure, surf, rocks, headlands, beaches, lagoons, deltas, and marshes.

8.2.4.1 Mangrove Ecosystem

In India, mangroves are distributed throughout much of the East and West Coast and on Andaman and Nicobar Islands. The mangroves of India are famous for their richness in the diversity of flora and fauna. The mangroves are vital and play a very important role in maintaining the ecosystem viable, and they also provide safety to the coastline communities and the property during natural hazards like cyclones, storm surges, and erosion. India is the first country to manage the mangroves scientifically, and the Sundarbans mangrove is the best example of it. The other mangroves of the East coast are found in the deltas of the Godavari, Krishna, Mahanadi, and Kollidam rivers and also in small patches along the coast. Mangroves cover about 4975 sq. km, which accounts for about 0.15% of the total geographic area of the country (ISFR 2019). The mangrove ecosystem has a considerable amount of biodiversity, and there are 5747 species, out of which 925 flora (Kathiresan 2018) and 4822 fauna (Chandra et al. 2019a, b) species are reported to be distributed in this unique ecosystem. The dominant mangrove species are *Avicennia officinalis*, *Excoecaria agallocha*, *Rhizophora mucronata*, and *Xylocarpus granatum.* The intertidal mudflats teem with migratory birds in winter; the dense mangrove forests provide habitat for the Bengal tiger. The seagrass beds of the ecosystem provide suitable habitat for the enigmatic and elusive sea cow (*Dugong*).

However, the mangroves are stressed because of various factors including the conversion of mangroves to other land-use types for urbanization, aquaculture, salt farming, mining, refineries, port/harbour, change in hydrological regimes, increasing salinity, coastal pollution, unsustainable fishing, cattle grazing, and inefficient institutional regimes (Kathiresan 2017, 2018). Additionally, the exclusive economic zone (EEZ), with a long coastline the country has a vast range of coastal ecosystems. Such regions are vulnerable to overexploitation of bio-resources, unplanned human settlements, improper location of industries, and pollution from industries and settlements.

8.2.4.2 Coral Reef Ecosystem

The coastal ecosystems of India are home to some of the most important and diverse coral ecosystems. There are four major coral reef areas in India, viz., Gulf of Mannar, Andaman and Nicobar Islands, Lakshadweep Islands, and the Gulf of Kutch. The coral reef areas are home to about 225 coral species. Additionally, few scattered coral growths are also present on the submerged banks along the west and east coasts of the mainland. These coral reefs of India are threatened because of several threats, including pollution, sea erosion, global warming, cyclones, and coral bleaching.

8.2.4.3 Estuarine and Lagoons

A network of about 14 major, 44 medium, and 162 minor rivers drain into the sea through about 53 estuaries distributed all along the east and west coasts of India providing habitat to a number of faunal as well as floral species and communities. Further, a total of 17 lagoons are also mapped on the coasts of India. These estuarine and lagoons are under tremendous pressure because of emerging pollution, unsustainable fisheries, global warming, cyclones, and encroachment for meeting the growing demand for land. The estuarine and coastal ecosystem also supports a number of seagrass species, which are vital for sustaining the population of conservation priority species, Dugong (*Dugong dugon*). About 14 species of seagrasses are reported from India. The endangered Dugong occupies the ecosystem, which is considerably rich in seagrass beds (Marsh et al. 2002) and has nutrient-rich calm water – generally located in the bays, shallow islands, and reef areas. The majority of the seagrass areas are located in the Gulf of Mannar, Palk Bay, Gulf of Kutch, and Andaman and Nicobar Islands (Kannan et al. 1999).

8.3 Protected Area Network

In India, for the in situ conservation, a network of 903 Protected Areas (PAs) has been established, extending over 165,012.59 km^2 (5.02% of the total geographic area), comprising 101 National Parks, 553 Wildlife Sanctuaries, 86 Conservation Reserves, and 163 Community Reserves. Out of these PAs, five are designated as World Heritage Sites by UNESCO. As the ecosystems and species do not recognize political borders, the concept of Transboundary Protected Areas has been initiated for coordinated conservation of ecological units and corridors with bilateral and/or multilateral cooperation of the neighboring nations. India's PAs grew by 15% since the adoption of the Programme of Work on PAs in 2002. In addition to the PA network, the Government of India has also notified other conservation areas, including the Tiger and Elephant reserves, under the flagship projects on tiger, elephant, and other species.

Further to the creation of new PAs, the government has also started monitoring the performance of the PAs through a national level scheme on monitoring and evaluation of PAs. The evaluation of PAs was initiated with the Tiger Reserves (TRs) in 2004 under the guidance of the Supreme Court of India, and the first report was published in 2006 on the evaluation of 28 TRs of India. However, Monitoring Management Effectiveness Evaluation (MEE) has become an essential exercise of MoEF&CC to understand how well the PA management is performing in addressing the wildlife conservation and management issues in PAs. A precise methodology was developed for conducting MEE of PAs in a phased manner. A set of 31 indicators were identified, and by following the World Commission on Protected Areas (WCPA) Framework for MEE, 6 elements were accounted for, viz., context, planning, inputs, processes, outputs, and outcomes using on which the MEE of PAs is conducted in India. The last report published by Mathur et al. (2015) not only provides the performance scores but also highlights the management strengths and weaknesses along with the immediately actionable point for the betterment of the PAs.

8.3.1 Sites of Conservation Importance

In addition to the PA network of India, a number of other areas have also been identified and prioritized for enhancing and securing the future of wildlife species. These conservation areas include Biosphere Reserves (18), Tiger Reserves (50), Elephant Reserves (32), Ramsar Wetland sites (37), Natural World Heritage Sites (7), Important Coastal and Marine Biodiversity Areas (ICMBAs) (107), Important Bird Areas (IBAs) (467), Key Biodiversity Areas (531), and Biodiversity Heritage Sites (18) (WII ENVIS 2020). These sites of conservation importance have been given various levels of legal protection through the Government of India and global conventions. The sites of conservation importance are distributed throughout the spatial extent of the country and host large populations of wildlife species of conservation priority.

8.4 National Wildlife Action Plan

The wildlife action plan provides a road map for addressing wildlife conservation and management challenges in the country. The first action plan was adopted in 1983 and was implemented up to 2001, and the second was from 2001 to 2016. Presently, the third National Wildlife Action Plan (NWAP) has been developed and is operational for implementation from 2017 to 2031 (NWAP 2017). The present plan outlines strategies and actions for addressing the wildlife conservation issues and challenges and also toward achieving the nature conservation targets and commitments both nationally and globally. The Government of India develops these national action plans with the support of subject matter experts, state forest departments, and professionals working towards wildlife conservation in India.

The Ministry of Environment, Forest and Climate Change, GoI, constitutes a committee of experts for conducting consultations for identifying the current issues and challenges to wildlife conservation in India. For example, the third or the present NWAP provides strategies to develop mitigation and adaptation strategies to address climate change for the first time, indicating that the NWAP is evolutionary in nature and provides a vision based on the prevailing conservation and management challenges. The adoption of a landscape approach from Protected Area-centric management is a key highlight of the present NWAP. Moreover, in the current scenario, increasing human-wildlife conflict is a major challenge for the managers throughout the spatial extent of the country. The third NWAP provides remedies and actions targeted toward addressing human-wildlife conflict and also strategies and ways to mainstream wildlife conservation in the development agenda of the country.

8.5 Status of Wildlife Conservation in India

Wildlife conservation lies in the cultural ethos of the country. We have a rich heritage of wildlife and a history of conserving the species since time immemorial. The ancient peoples of India had recognized the importance of wild animals and their coexistence. Hence, the majority of our cultural group's gods and our cultural leads were associated with animals. Even in the diverse art and craft, wildlife holds an important place, indicating its strong linkages with traditional practices. Indian communities have a history of worshipping animals such as tigers, elephants, and snakes. The British Raj in India was an era in India's history during which the majority of the wildlife was hunted and used as common property resources by rulers for their revenue needs and other purposes. A classic example is the extension of the cheetah from India in 1951 because of game hunting by the rulers of the princely States. But the stories of admiration of wildlife species as a god are still alive in our many cultural groups, which gives enough reason to protect them from extinction from the earth. However, after independence, the Government of India has taken serious steps towards conserving the wildlife of India. The game reserves were converted into National Parks and Wildlife Sanctuaries and other reserves with an aim to conserve species and sustain the viable population. The enactment of the Wildlife Protection Act (1972) has provided great support to wildlife conservation initiatives in India.

However, wildlife conservation in India is facing contemporary challenges. These challenges include unsustainable development, habitat encroachment, human-wildlife conflict, pollution of natural resources, and climate change. Hence, wildlife conservation has not been an easy job in history as well as in the present scenario where the country is one of the largest developing economies of the world. Over the years and decades, wildlife conservation problems have changed drastically. In present India, the human population explosive growth is a major conservation and management issue as the soaring demand for natural products such as timber, water, food, as well as land for human colonization has resulted in the destruction of India's natural resources and wildlife heritage. The ambitions of local communities to develop faster apar to the western world have drastically impacted the survival of wildlife in the recent past. The illegal hunting by communities for fetching economic dividends is seriously threatening charismatic wildlife species such as tigers, elephants, and many more.

Though the Government of India has taken up several stringent steps toward better conservation and management of wildlife in India, the formulation of NWAP in 1983 was among the critical step toward wildlife conservation in India. Over the past few decades, the NWAP has evolved to address contemporary wildlife conservation issues and challenges. The MoEF&CC has implemented a number of schemes and projects for the conservation and management of wildlife in India. Some of the recent and flagship schemes and programs are below:

1. Project Tiger/National Tiger Conservation Authority (NTCA).
2. Project Elephant.
3. National Biodiversity Action Plan/National Biodiversity Authority.
4. National Wildlife Action Plan 2017–2031.
5. India's global partnership (Convention on Biological Diversity, Convention on Migratory Species of Wild Animals, Convention on International Trade in Endangered Species, United National Convention to Combating Desertification, Cartagena Protocol on Biodiversity, United Nations Framework Convention on Climate Change, International Whaling Commission, RAMSAR Convention, IUCN-World Conservation Union, UNESCO World Heritage Program).

6. Creation of Wildlife Crime Control Bureau.
7. Integrated Development of Wildlife Habitats-Centrally Sponsored Scheme.
8. Species Recovery Programme (a total of 17 species are identified for the recovery program).
9. Establishment of Wildlife Institute of India, Dehradun, in 1982.
10. National Board for Wildlife in 2002.
11. Central Zoo Authority in 1992.
12. National Coastal Zone Management Authority.

8.5.1 Threatened Wildlife Species of India

India is home to more than 102,616 species of animals, which are distributed in 10 biogeographic zones of the country. A total of 6037 animal species have been assessed, and about 703 species are classified as threatened (IUCN 2020) (Fig. 8.1). A maximum number of 236 (33.57%) species belonging to fishes were listed under threatened species followed by 100 species of mammals (13.43%). About 92 species are classified as Critically Endangered, 216 species as Endangered, and 395 species as Vulnerable species (Table 8.1; Fig. 8.1) (IUCN 2020; IBAT 2020).

In addition to the animal species assessed by IUCN at the global scale, the MoEFCC, GoI, also gets the assessment of species at the state level under Article 38 of the Biodiversity Act (2002). These assessments are based on the

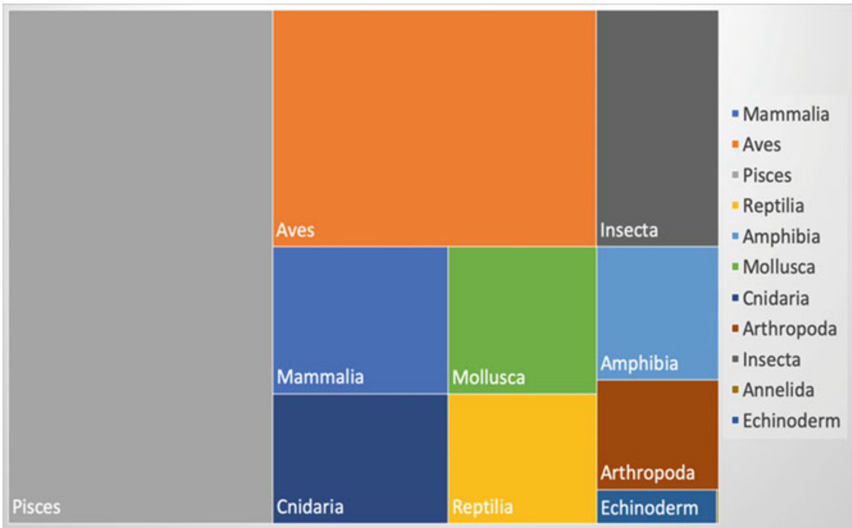

Fig. 8.1 Treemap graphical representation of different animal groups assessed under the IUCN Red-list version 2020–2022

Table 8.1 Classification of animal groups under different threat categories of IUCN Red-list version 2020–2022

Taxonomic group	EX & EW	CR	EN	VU	NT	LR/CD	LC	DD
Mammalia	0	12	41	47	26	0	269	32
Aves	0	17	21	62	82	0	1085	2
Pieces	0	29	86	121	71	0	1700	239
Reptile	0	10	16	29	11	0	176	68
Amphibia	0	20	33	22	9	0	98	86
Mollusca	0	0	3	4	1	0	255	97
Cnidarian	0	1	4	73	107	0	171	21
Arthropoda	0	2	6	15	4	0	104	91
Insecta	0	1	2	17	15	0	282	159
Annelida	0	0	0	0	0	0	1	0
Echinoderm	0	0	4	5	0	0	23	35
Total	0	92	216	395	326	0	4164	830

Red List categories: *EX* extinct, *EW* extinct in the wild, *CR* critically endangered, *EN* endangered, *VU* vulnerable, *NT* near threatened, *LR/CD* lower risk/conservation dependent, *LC* least concern, *DD* data deficient

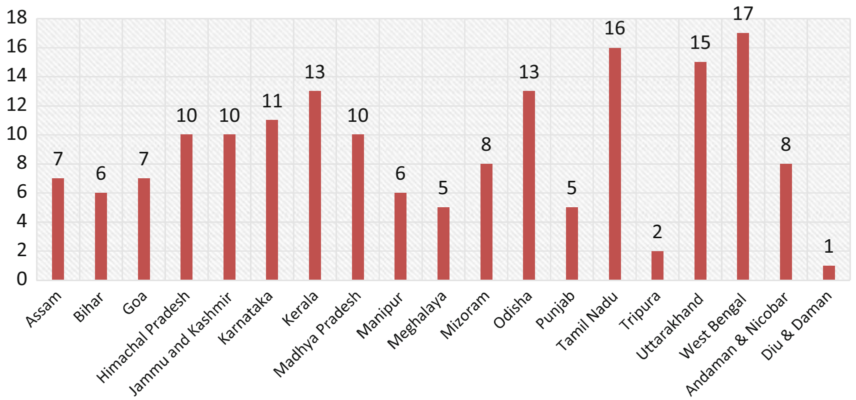

Fig. 8.2 Threatened fauna notified by the National Biodiversity Authority and State Biodiversity Boards

recommendations of the State Biodiversity and Wildlife Boards. The state authorities propose the list of species, and after consultation with the Zoological Survey of India, Kolkata, the MoEFCC finalizes the list for adoption under this act. These species are considered to be the most threatened and likely to get extinct in the absence of proper conservation and management action. The species notified under Article 38 by different state governments are given in Fig. 8.2.

8.5.2 Conservation Priority Species of India

Although there are about 703 threatened animal species distributed in various ecosystems of India, the majority of the conservation efforts have been prioritized on flagship/umbrella and keystone species. In the Himalayan region, the snow leopard has been prioritized as a flagship species for the conservation and management of the entire spectrum of species occupying the snow leopard distribution range. The Dolphin Project is launched on 15 August 2002 by the Prime Minister of India. Most recently, MoEF&CC has initiated the SECURE Himalaya project for the conservation of snow leopard and its associated species. In Peninsular India, the tiger has been prioritized for the conservation and management of the entire ecosystem. However, in addition to umbrella species, efforts have also been made for the conservation of species that need immediate action under the CAMPA scheme of MoEF&CC.

Population estimation of the tiger and its prey is the most extensive biodiversity survey carried out anywhere in the world. The fourth cycle of assessment was carried out during 2018–2019 using the most robust methodology. A total of 2461 individual tigers were photo-captured, which has resulted in a population estimate of about 2967 (SE range 2603 to 3346) (Jhala et al. 2019) (Table 8.2). The data indicated an increase in the population of tigers over the last four assessments in all landscapes.

Under the IDWH scheme of the Government of India, 17 faunal species have been identified for conservation planning. A species recover program has been initiated by MoEF&CC under the 11th plan period (2007–2011) and is under the different stages of implementation. The list of species identified under the scheme is given in Table 8.3.

Table 8.2 Population estimates of tigers in India (2010, 2014, and 2018)

Population estimates of tiger in India (2010, 2014, and 2018)			
States	2010	2014	2018
Shivalik-Gangetic	353 (320–388)	485 (427–543)	646 (567–726)
Central India and eastern Ghats	601 (518–685)	688 (596–780)	1033 (885–1193)
Western Ghats	534 (500–568)	776 (685–861)	981 (871–1093)
North East Hills and Brahmaputra	148 (118–178)	201 (174–212)	219 (194–244)
Sundarbans	70 (62–96)	76 (62–96)	88 (86–90)
India	1706 (1507–1896)	2226 (1945–2491)	2967 (2603–3346)

Jhala et al. (2011); Jhala et al. (2015); Jhala et al. (2019)

Table 8.3 List of species identified under the IDWH scheme

Species under the IDWH scheme	
1. Asian wild buffalo	10. Jerdon's courser
2. Asiatic lion	11. Malabar civet
3. Brow-antlered deer or sangai	12. Marine turtles
4. Dugong	13. Nicobar megapode
5. Edible-nest swiftlet	14. Nilgiri tahr
6. Gangetic river dolphin	15. Snow leopard
7. Great Indian bustard	16. Swamp deer
8. Hangul	17. Vultures
9. Indian rhino or great one-horned rhinoceros	

8.6 Conservation and Management Issues and Challenges for Wildlife in India

8.6.1 Human-Wildlife Conflict

The human-wildlife conflict (HWC) is a major conservation challenge faced by managers in India. The HWC can be classified into three types, i.e., crop depredation, livestock depredation, and human attacks by wildlife species; among the three, attacks (human injury/fatality) on humans are the most acute. The local communities that are underprivileged and spread over the forest fringes are the most impacted by HWC. The HWC also leads to economic loss by way of crop damage and livestock depredation by large carnivores and mega-herbivores. The intensity of the conflict has increased through the wildlife-human interface in the country, and it greatly impacted the conservation and management actions taken by the governments. Furthermore, increasing HWC is leading to the development of antagonistic behavior among the local communities towards the wildlife species. A number of studies have highlighted that HWC is leading to retaliatory killing of species and lethal removal of species (Charoo et al. 2011; Joshi et al. 2020).

The HWC is acute when the species involved is highly imperilled, while its presence in an area poses a severe threat to human welfare (Saberwal et al. 1994). Although humans and carnivores have co-existed for a long time, the frequency of negative interactions has increased in the recent decades as a result of human activities in wildlife areas or in natural habitats (Graham et al. 2005; Bulte and Rondeau 2005). Multiple studies have shown that carnivore populations are limited by human interventions (Charoo et al. 2011; Banerjee and Jhala 2012), and HWC may lead to local extirpation of species. Conflicts with people have led to the extinction and eradication of certain wild species (Woodroffe et al. 2005). The human-induced mortality not only affects the population viability of some of the most endangered species but also has broader environmental impacts on ecosystem equilibrium and biodiversity preservation.

The expansion of human influence and ever-increasing pressure on natural resources has dramatically intensified the issue of human-wildlife conflict in a wide variety of situations. The carnivore-human conflict is a global problem for wildlife management (Hoogesteijn et al. 1993; Rajpurohit and Chauhan 1996; Linnell et al. 1996; Mizutani 1999; Butler 2000; Bauer and Kari 2001; Stahl et al. 2001; Karanth and Madhusudan 2002, Chauhan et al. 2002). All large cats such as lion, tiger, snow leopard, and leopard are involved in conflicts with humans or with the livestock in the country (Chakrabarti 1992; Chellem and Johnsingh 1993; Sabarwet et al. 1994; Daniel 1996; Mishra 1997; Jhala and Sharma 1997; Jackson 1999; Rangarajan 2001; Mishra et al. 2003).

However, when large cats live in proximity to humans, some level of conflict between them is inevitable (Sawarkar 1986). Similarly, in the Himalayas, black bear-human interactions have been reported in the past (Prater 1980), but the intensity of such reports has been increased in recent years (Sathyakumar and Choudhury 2007; Charoo et al. 2011; Sathyakumer et al. 2012). The elephant-human conflict is a serious conservation and management problem throughout its range and corridors in India as well as elsewhere in Asia. Moreover, elephant-human conflict is a transboundary issue in the Central Himalayan landscape between India, Nepal, and Bhutan. In addition to elephants, other mega-herbivores, including rhino and gaur, are also involved in conflicts with humans in the North Bengal Region, which is primarily attributed to their increasing population and inadequate carry capacity of the Protected Areas in the landscape. The rhino and gaur come out of the PAs in the surrounding areas resulting in crop-raiding incidences. This results in the development of negative attitudes among the local communities towards the species. The other species which are more predominantly involved in conflict include nilgai (*Boselaphus tragocamelus*), wild boar (*Sus scrofa*), blackbuck (*Antilope cervicapra*), and rhesus macaques (*Macaca mulatta*). The primary factor behind the increasing instance of HWC in the recent past includes habitat loss, habitat fragmentation, agricultural expansion, increase in the population of few herbivores, depletion of natural food resources, and climate change.

8.6.2 Conversion of Forest to Other Land Uses

The conversion of forest land use to other land uses is a growing concern in India and throughout the globe. It results in ecological effects as well as socioeconomic effects, and the major driver of the conversion of forests to other land uses includes agricultural expansion and human colonization. The conversion of forests to other land uses not only has implications to the survival of wildlife species, but the consequences are more dramatic on the overall ecosystem, climate change mitigation potential, increasing evapotranspiration, surface runoff, and forest hydrology (Dinkinson 1991; Nemani and Running 1995; Houghton and Hackler 2000). Deforestation and degradation may also result in changes in plant and animal community structure, which can drastically impact the ecosystem services (Mladenoff et al. 1993). However, the impacts of forest land use on other land uses could have far-reaching implications for wildlife conservation, including HWC and loss of population viability of species (Okello and Wishitemi 2006; Joshi et al. 2020).

8.6.3 Habitat Degradation and Fragmentation

Habitat destruction is the leading cause of extinction and also leads to the population decline of the species; consequently many species of global importance are placed under varying degrees of threat. The drives of degradation can be classified into indirect or the underlying cause and direct or proximate causes. The indirect drivers are primarily an interplay of demographic, economic, technological, institutional, and socio-cultural factors that underpin the direct drivers of deforestation. The degradation and fragmentation of habitat are one of the major conservation and management issues pertaining to wildlife conservation in India and elsewhere. As it results in a decline in the wildlife population, an increase in HWC, loss of genetic diversity and connectivity among the populations, and loss of biological corridors greatly impact the landscape utilization patterns of species. According to Kruess and Tscharntke (1994), habitat fragmentation in the agricultural landscape is a major threat to biodiversity, especially to insects and other lower invertebrates. The creation of the small forest fragments in the form of patches leads to biodiversity loss since fragmentation stops various ecological processes such as gene flow and consequently leads to bottleneck and extirpation. The population demographic trends, isolated distribution, and shrinking habitats indicate a decline in primate populations in Northeast India (Indo-US primate project 1994–1999). Nine species of non-human primates, namely, the hoolock gibbon (*Bunopithecus hoolock*), golden langur (*Trachypithecus geei*), capped langur (*T. pileatus*), Phayre's langur (*T. phayrei*), stump-tailed macaque (*Macaca arctoides*), Assamese macaque (*M. assamensis*), pig-tailed macaque (*M. nemestrina*), rhesus macaque (*M. mulatta*), and slow loris (*Nycticebus coucang*) all of them are significantly impacted by habitat loss, and their populations are getting isolated and fragmented which is a potential threat for their long-term viability (Srivastava and Mohnot 2001).

The fragmentation of forests is usually due to unsystematic removal and the conversion of forests to different land-use patterns, which results in the reduction of the genetic exchange of flora and fauna. Trees with a restricted range of their pollinators to cross are subjected to inbreeding and loss of genetic vigor and variability. The changes as a result of fragmentation in microclimate impact not only on the distribution of species of animals and plants but also on the biological spectrum. It is observed that there is tree mortality near edges, besides the replacement of climax species by pioneer species. According to Gascon et al. (2000), these effects can be seen as far as one kilometer into the forest. The drier conditions coupled with drier biomass of plants, particularly that of gregarious growth of invasive species such as *Chromolaena odorata*, *Hyptis suaveolens*, *Lantana camara*, etc., make the fragment vulnerable to the frequency of fires. There is an immediate need not only to stop any further habitat loss but also to restore a substantial fraction of the perforated habitats in terms of connectivity, which are under threat and have declined drastically. The major causes of habitat loss and fragmentation include deforestation, expansion of transitional landscapes, mining in forest areas, forest parcelization, large-scale dams, and power projects.

8.6.4 Forest Fire

Forested habitats are a major natural resource, and they play an essential role in maintaining ecological balance and biodiversity conservation. The health of a forest in any given area is a true indicator of the ecological conditions prevailing in that area. Globally forest fires have been recognized as a major driver of the degradation of forests and are considered to be a possible hazard with physical, biological, ecological, and environmental consequences (Filippidis and Mitsopoulos 2004). In India, forest fires are the most significant and steadily increasing degradation process, although the extent of total damage is not well documented. However, it is estimated that the proportion of forest areas prone to fire annually ranges from 33% in some states to over 90% in India (Roy 2004). Forest fire destroys all life forms at different levels of the organization; for example, ground fire destroys the organic matter, which is needed to maintain an optimum level of humus in the soil. The tree saplings and seedlings get destroyed completely, impacting the regeneration process, and severe fire sometimes destroys ladder fuel as well as the crown of fully grown tree species (Mallik and Gimingham 1985). The forest fire has become a recurring phenomenon in the Indian forest, causing immeasurable damage to the forest's wealth and ecosystem. As a silviculture practice, controlling fire, though may help in managing ecosystems, uncontrolled fires contributed to substantial loss to biodiversity, soil fertility, and sustainable forest base production.

The direct effects of fire on animals vary among the different taxonomic groups. Agile animals can flee to refugia within the fire, such as termite mounds, or move across the fire line to places of safety (Bond and Keane 2017). The herpetofauna may suffer higher mortalities, and severe fires can also impact large mammalian species. The impacts of forest fires in India are mostly undocumented, and it has been one of the understudied subjects. Not much effort has been made toward developing a methodology to assess the impacts of forest fires on faunal diversity. Until now, the impacts of forest fire on biodiversity are evaluated in terms of area burned and the amount of timber destroyed in forest stands. Hence, there is a need to develop a standard methodology for estimating the amount of biodiversity, especially the loss of faunal elements due to forest fires.

8.6.5 Unsustainable Utilization of Forest Products

All through the forest and wildlife provide enumerable goods and services for human beings even though they are facing a formidable array of threats that are attributable to peoples. These include unsuitable harvesting or collection of fuel wood, non-timber produces, overgrazing, illegal wildlife hunting for bushmeat and trade, encroachment, and unsustainable tourism and recreational pressures. Globally, the reasons for the unsustainable extraction of forest produce are attributed to poverty, increasing consumption by wealthier populations, insecure land tenure, socioeconomic inequality, and system corruption (Kaeslin and Williamson 2010).

8.6.6 Climate Change

In India, climate change is posing a real challenge by impacting agriculture, forests, water resources, and health. The impacts are more profoundly felt in India due to the increasing population putting pressure on the natural resource base and low financial adaptive capacity. During 1990–2000 about 664 million people were affected by droughts in Asia, of which more than half of it is reported from South Asia. India accounted for about 59%, the highest number of people affected, followed by China by about 26% (Acosta-Michlik et al. 2008). It is a severe concern for biodiversity in the rainfed area, especially in the Himalayas and drylands of India.

Furthermore, studies have reported stress on water tower regions throughout the world in general but especially in the transboundary Himalayan region. Due to climate change, glaciers are melting rapidly, leading to their shrinkage and also leading to the formation of glacial lakes, which can potentially lead to glacial lake outburst floods in plains (Gosain et al. 2006). An increase in extreme weather events (heat and cold waves, high rainfall events) makes the wildlife species vulnerable to extirpations and extensions.

Ravindranath et al. (2006) predicted a shift in forest types due to climate change and the corresponding reduction in forest produce and livelihood prospects by the year 2085. Similarly, ICFRE (forest types of India: Revisited 2013) reported that climate change is leading to change in the community composition of plant species in many regions, especially in the Himalayan and the hill states of northeastern India. Already the compelling evidence of climate change impact is visible on a wide range of taxonomic groups of species (birds, mammals, insects, and plants) (Learmonthe et al. 2006; Robinson et al. 2009; Bagaria et al. 2020). It is leading to changes in the timing of migration, population size, and distributions (Crick 1999; Sims et al. 2001; Berry et al. 2001). Recent changes in climate have influenced plant ecology worldwide (Parmesan 2006). Most profoundly in the Himalayan region, climate change has become an irrefutable threat to a variety of wildlife species, especially those with a narrow ecological niche, and is at higher extinction risk. However, studies have brought out that both the specialists and the generalist species may decline due to the climate change (Fordham et al. 2012; Forrest et al. 2012; Chhetri et al. 2018; Wilkening et al. 2019).

Furthermore, empirical studies have established that climate change not only results in shifting the ranges/boundary but also impacts the core regions (Hannah et al. 2019; Noce et al. 2019; Bagaria et al. 2020). Impacts are expressed in the form of a range of contractions or extinction of populations because of hostile environmental conditions and expansions because of dispersal into newly favorable habitats (Brown and Yoder 2015; Osland and Feher 2019; Bagaria et al. 2020). Hence, it is imperative to build resilience to combat climate change by developing adaptability and mitigation strategies by mainstreaming climate change in all development sectors.

8.6.7 Invasive Species Infestation and Habitat Degradation

Like all natural ecosystems, India's native habitats have developed a complex system of checks and balances that prevents the overpopulation of plant and animal species and maintains a healthy natural environment. However, due to globalization and improvement in transport systems, non-native species have been introduced into new areas accidentally and intentionally (Richardson et al. 2003; Ruiz and Carlton 2003). The intentional introductions of non-native species are primarily motivated by economic, environmental, and social considerations.

The invasive alien species (IAS) are threatening the wildlife habitat by changing the species composition in the forest communities (McNeely et al. 2001). However, at the ecosystem level, IAS are threatening the trophic structures because they can potentially change the availability of resources such as water and nutrients and alter the disturbance regimes (McNeely et al. 2001; Petit et al. 2004). Throughout the forested landscapes of India, *Lantana camera* has made itself indispensable, which may have negative impacts on the wildlife population. The *Lantana camera* has been listed among the top 100 "World Worst" invaders (Lowe et al. 2000). The negative impacts of IAS have been documented throughout the globe (Monney and Hobbs 2000; Chomesky and Randall 2003; GISP 2006, 2008). The other plant species which are threatening the terrestrial wildlife habitat include *Prosopis juliflora*, *Mikania micrantha*, and *Parthenium hysterophorus*, whereas in the aquatic ecosystem, there are about 324 non-native species of fishes introduced including the ornamental, cultivable, and larvicidal fishes (Mandal 2011). However, the populations of the native fauna of the aquatic ecosystems are threatened by invasive fish species such as brown trout (*Salmo trutta fario*), rainbow trout (*Oncorhynchus mykiss*), common carp (*Cyprinus carpio*), and African catfish (*Clarias gariepinus*) (Lowe et al. 2000; Krishnakumar et al. 2011; Johnson et al. 2014). There is a need to address the issues of IAS for the long-term viability of habitats and the population of native species by adopting the best practices for prevention and controlling the invasive species in the various ecosystems of India. The Forest management working plan, as well as the Protected Areas management plan, should have sufficient remedies to combat the infestation of IAS.

8.6.8 Competing Development Needs in an Emerging Economy

The major drivers causing biodiversity loss and depletion of ecosystem services are steadily increasing and are primarily associated with the development agenda. In India, the major demands on biodiversity are due to demographic pressures, poverty, cultural and religious mores, and competing development needs. The degradation of land and the associated ecosystems due to the conversion of forest land to intensified agriculture, invasive species infestation, and nutrient loading cumulatively influence the ecosystem services. In developing countries such as India, the most significant factor for the worsening of ecosystem services is the growing need for food and water for a continuously burgeoning population. The natural resources, including the wildlife species and their populations, are getting impacted by the developmental projects coming up on forest lands. It is resulting in habitat fragmentation and loss of genetic connectivity among the populations of wildlife species. In the present scenario, the overarching ambitions of Indian society to develop apar to other leading economies are resulting in squeezing the natural habitats of species. Increasing HWC is a major outcome of habitat loss because of developmental projects such as linear road/railway projects, hydropower dam projects, and other infrastructure projects. However, sustainable development can enable the integration of economic growth and environmental stewardship and must be the principal and operational standard. It has been realized that all sorts of developmental activities impact ecosystems, while the ecosystems sustain sustainable development. Hence, biodiversity should be at the center of economic activities for the smooth flow of ecosystem services. In this context, the United Nations Sustainable Development Goal 15 Life on Land is fundamental for the viability of wildlife species in terrestrial ecosystems.

8.6.9 Pollution in Ecosystems

The pollution of natural ecosystems, including terrestrial, aquatic, and marine, has been identified as a major conservation and management issue. The effects of pollution on wildlife include direct mortality, debilitating industrial-related injury and disease, physiological stress, and bioaccumulation. Moreover, air pollution near the forested habitat can even lead to changes in the plant and animal community structure. The Government of India has established environmental standards for various industrial sectors under the Environmental Protection Act (EPA), 1986. But, pollution is a significant issue throughout the country, impacting the range of ecosystems from sea to forest ranges. Most recently, micro-plastic pollution in the marine ecosystem has been identified as a severe threat to marine life because it carries toxins that concentrate contaminants. In such a concentrated contaminated area, the animal ingests contaminants along with the plastic, which potentially gets absorbed in tissue and later gets transported in the marine food chain, thereby impacting the entire ecosystem. The wildlife species are susceptible to sound pollution, as anthropogenic noise greatly impacts the various aspects of animal physiology and development (Kight and Swaddle 2011). The anthropogenic noise can directly impact the reproductive success of various wildlife species. For example, anthropogenic noise interferes with the mating calls of birds and herpetofauna in the urban landscape, which impacts the breeding success of the species.

8.7 Strategies for Long-Term Viability of Wildlife in India

Considering the issues and challenges to wildlife conservation in India, we suggest a few specific strategies given below:

1. **Charismatic species and beyond**: In addition to charismatic species such as tiger, lion, snow leopard, and elephant, there is a need to develop conservation programs for the species, which are also on the verge of extinction. Insignificant efforts have been made on such species even though many of them are listed among the Critically Endangered and Endangered species. Moreover, these are not well scientifically studied, and much of their ecology and behaviour are unknown.
2. **Adaptive spatial planning of conservation areas**: Adaptive spatial planning is vital in the present scenario for the long-term viability of species that are threatened because of climate change and forest land-use conversion. It is projected that the species will shift to favorable areas because of changes in climatic isotherms. Hence, such areas should be identified using the climate change projection for adaptive planning of the Protected Area Network.
3. **Mapping and improving the biological corridors**: The mapping and habitat quality improvement of biological corridors are imperative in mitigating the threats posed by development projects, specifically the linear development project.
4. **Adoption of new techniques and advanced tools**: New tools and methods can improve our understanding of ecosystems and species. The use of eDNA metagenomics can enhance our understanding of the ecosystems for making informed conservation and management actions. Besides, the use of soundscape ecology for understanding the species community associations and discovering cryptic species will provide new insights at the ecosystem scale.
5. **Integrated financial system for wildlife conservation**: In addition to the centrally sponsored schemes (CSS) of the Government of India for the conservation of wildlife, there is a need to develop an integrated financial framework (IFS) for financing wildlife conservation research. The IFS can be used for mobilizing funds for the implementation of necessary conservation actions. The national as well as international funds, which directly and indirectly contribute to biodiversity conservation, may be integrated into a framework for achieving conservation goals.
6. **Convergence among global initiatives, processes, and commitments:** The international community and multilateral institutions now recognize the imperatives of sustainable management of ecosystems, and wherever possible efforts are made to restore their ecological productivity and biodiversity. The three Rio Conventions, UNCCD, CBD, UNFCCC, and international organizations that are working towards sustainable development and biodiversity conservation are well-positioned to assist countries in their quest for enabling policies, support, and approaches that address both the causes and effects of biodiversity loss. The convergence of the objectives outlined by the Conference of Parties (CoP) of

these international conventions will encourage effective policy and investment approaches. Hence, in order to make the most of these synergies, it is essential that collaboration and coordination begin at the level of implementation.

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Chapter 9
Indian Avian Diversity: Status, Challenges, and Solutions

Asad R. Rahmani

9.1 Introduction

BirdLife International, the world's premier bird and nature conservation organization with partners in 120 countries and territories, has recognized 11,000 bird species in the world (del Hoyo and Collar 2014, 2016). In the territorial limits of India, Praveen et al. (2016) recognized 1262 bird species, but soon after that, many more species were added to this list, so now the list stands at about 1210 species (Praveen et al. 2019). Almost 14 percent of the world's birds and a similar number of India's bird species are under threat of extinction. As per BirdLife International, 168 Indian birds have been identified in the Threatened and Near Threatened categories of the IUCN Red List (BirdLife International 2020).

Besides the usual threats of habitat destruction and hunting, there are many emerging threats to birds and other biota and their diversity the world over. Some of these threats are country-/region- or species-specific, but most of them are generic and apply to almost all birds. This paper deals with emerging new threats to Indian avian fauna and give examples and recommendations to prevent the threats. As the paper is meant for graduate students, scientific jargon is avoided. The paper is based on the authors' own fieldwork, discussions with national and international bird experts, and literature surveys.

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9.2 Red List of Bird Species of India

Every year, the International Union for Conservation of Nature (IUCN) brings out a Red List of flora and fauna that identifies species in danger of extinction in the immediate and long-term future. The Red List of Threatened Species, founded in 1964, is the world's most comprehensive inventory of the global conservation status of biological species. It uses a set of criteria to evaluate the extinction risk of thousands of species and subspecies. BirdLife International is a nodal agency of the IUCN for preparing bird Red List. The Red List has the following categories which need to be understood before we discuss the emerging threats to birds.

- Extinct (Ex) – the species is extinct.
- Extinct in the Wild (EW) – the species is present in captivity, cultivation, or outside its normal range but extinct in the wild.
- Critically Endangered (CR) – in an extremely critical stage, the species may become extinct in three generations or less.
- Endangered (EN) – very high risk of extinction in the wild and meets any of criteria A to E.
- Vulnerable (VU) – meets one of the five Red List criteria and thus considered to be at high risk of unnatural (human-caused) extinction.
- Near Threatened (NT) – close to being at high risk of extinction in the near future.
- Data Deficient (DD) – not much information available but likely to be in Threatened category.
- Not Evaluated (NE) – no status assessment done.
- Least Concern (LC) – unlikely to become extinct in the near future.
- CR, EN, and VU species come in the Threatened Category, according to IUCN Red List.

According to BirdLife International, out of a total of 168 birds in the Threatened and Near Threatened categories of IUCN, 16, 20, and 57 belong to critically endangered, endangered, and vulnerable categories (BirdLife International 2020; et al). A few examples are given below:

Extinct: Mountain quail (*Ophrysia superciliosa*) and pink-headed duck (*Rhodonessa caryophyllacea*) are considered extinct.

Extinct in the Wild: We do not have a bird in this category in India.

Critically Endangered: Seventeen species come in this category, including four species of vultures and great Indian bustard (*Ardeotis nigriceps*), Bengal florican (*Houbaropsis bengalensis*), Bugun liocichla (*Liocichla bugunorum*), Siberian crane (*Leucogeranus leucogeranus*), Jerdon's courser (*Rhinoptilus bitorquatus*), and Baer's pochard (*Aythya baeri*).

Endangered: Twenty-one species, including Egyptian vulture (*Neophron percnopterus*), white-winged duck (*Asarcornis scutulata*), lesser florican (*Sypheotides indicus*), greater adjutant (*Leptoptilos dubius*) and others, may come in this category.

Vulnerable: Sixty-three birds are listed here. Some of the well-known ones are sarus crane (*Antigone Antigone*), Nicobar scrubfowl (*Megapodius nicobariensis*), Western tragopan (*Tragopan melanocephalus*), Blyth's tragopan (*Tragopan blythii*), Nilgiri wood pigeon (*Columba elphinstonii*), and white or pale-capped pigeon (*Columba punecea*).

In the **Near Threatened** category, 81 species are listed. The list is too long to be mentioned here.

In India, three birds are considered as **Data Deficient**: white-faced plover (*Charadrius dealbatus*)¸ large-billed reed warbler (*Acrocephalus orinus*), and Sillem's Rosefinch (*Carpodacus sillemi*).

9.3 Protection Measures

There are more than 700 protected areas in India in the form of the national park, sanctuaries, community reserves, and conservation reserves. Within these four categories, some areas are recognized as Tiger Reserves (52), Ramsar Sites (37), and/or World Heritage Natural Sites (7). In 2004, BirdLife International and Bombay Natural History Society identified 445 Important Bird Areas (IBAs) in India (Islam and Rahmani 2004). In 2016, this list was revised and updated by Rahmani et al. (2016), and now 554 Important Bird and Biodiversity Areas have been identified.

Most of the wild Indian birds are protected under the Wildlife Protection Act (1972) (modified and updated many times since 1972). Killing, hunting, trapping, and trade of all Indian wild birds are totally prohibited except under the license given by a state's Chief Wildlife Warden. Many wild birds get protection in the Protected Areas, Ramsar Sites, IBAs, and Tiger Reserves. There are about 200 sanctuaries specially created for the protection of birds. These are generally wetlands such as Keoladeo National Park in Rajasthan, Chilika Lake in Odisha, Pong Dam in Himachal, Shallabugh and Hokarsar in Kashmir, and Nalsarovar in Gujarat.

9.4 Emerging Threats of the Indian Birds

As mentioned in the beginning, habitat destruction/deterioration and shooting/trapping are the major threats to Indian birds that are well known, so it need not be discussed. In this paper, we will discuss the emerging threats that need the immediate attention of conservationists, researchers, wildlife managers, and the government. There are some more threats such as oil spills, invasive species, and bird collisions with tall glass panel buildings, but as they are minor threats in India or not much research has been done in India, we will not discuss them in detail. The emerging threats include wind farms, power line collisions, free-ranging stray dogs, climate change, plastic pollution, pesticides, and sand mining.

9.4.1 Wind Farms

Man-made infrastructures such as wind farms, solar panels, and power lines have a major impact on birds in the form of mortality, habitat loss, change of behaviour, disruption of the breeding cycle, and disruption of migratory paths. Interestingly, wind farms are considered "green energy," and even an environmental impact assessment is not required before wind farms are set up. The idea is to harness wind energy and convert it into electricity. It is not only the presence of the individual wind farm that occupies a small area but the associated infrastructure such as roads and transmission lines that can result in extensive habitat fragmentation and spread of invasive species. Wind farms are generally established on the crest of hills and those places where the wind is strong – these are the areas that birds and bats use for migrating. Even ground-living lizards and snakes are impacted, due to habitat and ecological changes, disruption of predator-prey relationship, and their cumulative cascading effects.

It was earlier thought that only large birds such as eagles, cranes, bustards, storks, ducks, and swans are killed by the blades of the wind farms and associated power lines, but now it has been found that even small passerines are killed in very large numbers (Mohibuddin 2017). Not much work has been done in India on the impact of wind farms, but studies in the USA and Europe prove that passerines and waders, particularly nocturnal migrants, suffer huge collision fatalities (Osborn et al. 2000; Mabee et al. 2006). Sometimes, the passerines can comprise more than 80% of all bird collisions (Erickson et al. 2002). For more information on the impact of wind farms on birds and bats, I suggest readers to refer to ENVIS Bulletin which was brought out by the Bombay Natural History Society and is available on the Internet (Narwade et al. 2013).

There is a need for studies with pre-and post-construction data to determine whether wind facilities will have detrimental effects on avian groups such as raptors and other soaring birds. Already existing windmill sites should be monitored closely to measure bird mortality, analyze the factors that lead birds to fly close to turbines, and propose mitigation measures. Instead of erecting wind farms in forests, grasslands, or even off-shore, it is better to erect them in areas that are irreversibly damaged by human activities.

9.4.2 Threats of Power Lines

There is increasing scientific literature on the impact of power lines on large flying birds such as bustards, storks, eagles, and cranes. Cranes and bustards have a visionary block in front of their head due to the placement of their eyes on the sides. These large birds are particularly prone to collision due to their low maneuverability during flight and/or poor forward-facing visual vision. While flying fast, by the time they see a high-tension wire, it is too late. Either they are injured or electrocuted or both. The large bodies touch two wires which result in electrocution. For example, in Spain, it has been proved that collision from power lines is the major problem for the great bustard (*Otis tarda*) (Alonso et al. 1994; Janss 2000; Martin and Shaw 2010; Martin 2011). A study on the whooping cranes (*Grus americana*) found that when the juveniles migrate from Canada to Texas in the USA, many juveniles die after the collision as they are unfamiliar with the landscape (Stehn and Wassenich 2008). They have mentioned 45 documented cases of mortality of whooping cranes from a collision. Reduced visibility in foggy conditions also results in high collision of flying birds. In North India, during winter there are many foggy days when the visibility is less than 50 m. Sundar and Choudhury (2005) were the first to highlight the threat of overhead wires to the sarus crane. In a study based in Mainpuri and Etawah districts, they found that 1% of sarus die every year after hitting the wires. In a 2-year study on sarus crane in seven districts of Uttar Pradesh, Rahmani et al. (2019) found that many cases of sarus death are by collision by power lines. Tere and Parasharya (2011) reported the death of 150 flamingos (*Phoenicopterus roseus* and *Phoeniconaias minor*) in Gujarat.

In a detailed study on the impact of power lines on birds, Mohibuddin (2017) found that about 18,700 birds are dying per month in the Thar landscape in Jaisalmer. Collision per crossing was higher for high-tension power lines with multiple wires. Mohibuddin (2017) shows that power lines are affecting a wide range of bird species; therefore, it is necessary to develop bird-friendly infrastructures to fulfill human requirements without endangering birds as well as implementing a regular power line mortality monitoring programme to assess the effectiveness of these measures. Based on their studies of power lines and the great Indian bustard (GIB) movement, the WII found four great Indian bustard carcasses under power lines in the Thar Desert. Extrapolation of their findings on total high-tension power lines under prime GIB habitat of Thar indicates that about 18 great Indian bustards/year are dying due to power line casualties.

There are various methods such as deflectors that can prevent collision as they make the high-tension wires more conspicuous to flying birds. In some critical areas, wires should be put underground.

9.4.3 Free-Ranging Dogs: New Apex Predator of Indian Countryside

All birds have their own natural predators, but now dogs have become a major threat to numerous species. There could be one billion dogs, both domestic and free-ranging, in the world. While domestic dogs or pet dogs have little impact in the countryside, 500–700 million free-ranging stray dogs have now become the apex predator of the countryside for a large variety of wildlife. India has the highest number of free-ranging domestic dogs in the world (Gompper 2014). Domestic dogs are called free-ranging dogs when they are not under direct human supervision (leashed and listening to humans) and whose activities are not influenced by human activities (Cafazzo et al. 2010). Along with cats and rodents, dogs are the most notorious invasive species in the world. Doherty et al. (2017) estimated that worldwide, free-ranging domestic dogs cause potential risk to nearly 200 vertebrate species listed in the Red List of IUCN. Home et al. (2017) based on the online key informant survey and reports from national print media in India found that dogs attacked 80 wild species, including 31 IUCN Red List threatened species, of which 4 are Critically Endangered. In another study in India, it was found that free-ranging dogs are the main predator of wildlife in the Thar Desert (Bhardwaj et al. 2018).

Studies conducted by Mohandas (2017) in the Thar Desert of Rajasthan show that the free-ranging dogs now act as the apex predator in the Thar landscape, and compared to other apex predators, they occur at much higher densities, to the tune of 1.79 $\pm$ 0.46 individuals per km^2, resulting in 1804 dogs in 1008 km^2. They were estimated to kill about 30% of the chinkara (*Gazella bennettii*) population every year which is the predation pressure that no low-density animal can sustain. The study has recommended a sustained sterilization program (Mohandas 2017).

Free-ranging stray dogs are a direct threat to ground-nesting and wetland birds. Rahmani et al. (2019) in a study on the sarus crane (*Grus antigone*) in central Uttar Pradesh found dogs disturbing the sarus or very close to sarus with chicks/juveniles on 26 occasions.

The threat of free-ranging stray dogs could be two major categories:

1. **Predation**: A dog killing a wild or domestic animal.
2. **Disturbance**: It can be subdivided into two types:
   (a) Direct disturbance: Harassment by dogs to wildlife. For example, Rahmani et al. (2019) found that, many times, sarus leaves the area when dogs appear or remain distressed for a long time. Lenth et al. (2008) have shown the negative impact of stress and energetically costly behaviour of wildlife in the presence of dogs. Fear-mediated behavioural changes in the presence of predators can also decrease breeding success in some species (Zapata-Ríos and Branch 2016).
   (b) Indirect disturbance: Frequent presence of dogs in an area forces many wild species to leave the area. For example, a study near Sydney, Australia, found that pet dogs, even when restrained by a leash, walking in city parks and national parks, reduce the abundance and species richness of birds (Banks and Bryant 2007). They have shown that dog walking in woodland leads to a 35% reduction in bird diversity and a 41% reduction in bird abundance.

9.4.3.1 Managing Dog Problem

Managing free-ranging domestic dogs is an intricate social, religious, ecological, and cultural problem. On top of this is the issue of disposal of waste generated by human beings. It is a misnomer to call free-ranging stray dogs feral as a definition of a feral is a domestic animal gone totally wild in many generations. The dogs that we see all around in cities, villages, and the countryside are not feral dogs but domestic dogs living more or less a free life with or without a human owner. They roam in the countryside, killing wild animals, but most of them freely accept human presence, unlike a feral animal which runs away from a human being like any wild animal. These free-ranging dogs also partially depend on human-provided food or garbage dumps. Their numbers and distribution, therefore, are more or less dependent on human beings. As urbanization and settlements expand, such dogs will also spread to newer and newer areas.

9.4.3.2 What Is the Solution?

Culling of free-ranging stray dogs is the best and most effective solution, but it is socially unacceptable. Desexing or sterilization is a long-term solution, but it has to be done on a massive scale. Sterilizing even 30–40% of the dogs of an area does not solve the problem – we have to reach 80–90% of the sterilization target before any results are seen. Moreover, sterilizing male dogs does not solve the problem as subordinate male dogs take over quickly. Sterilizing bitches are more important, but it is time-consuming and the animal has to be kept in care for 2–3 days.

Reducing access to food waste is a good solution, but it needs a massive overhaul of administrative measures and behavioral change in society. In a country where even cities are not kept clean, despite a huge army of cleaning staff, it will be too much to expect to keep the countryside clean!

9.4.4 Climate Change

The topic of climate change is too well known to need any introduction. There is a huge body of literature and hundreds of institutions, universities, NGOs, and scientists/social scientists working on the subjects. Governments, including India, have taken measures to mitigate the negative impact of climate change on the environment, people, and wildlife. Here I will briefly describe the impact of climate change on birds, giving examples of birds found in India.

Most birds have a delicate energy balance, and their survival and breeding depend on maintaining this energy balance that is influenced by the food that they are able to procure. The food in the form of insects, fish, seeds, fruits, flowers, and vertebrate prey depends on the habitat quality, weather, and climate. The timing of egg-laying and the chick-growth period is affected by annual variation in weather. This is particularly important for temperate and Arctic breeding birds (that migrate to India in winter). It has been shown in many studies that, due to climate change, there is a mismatch between the arrival of migratory birds, their breeding, and the peak population increase of insect prey (Meltofte et al. 2007). Birds time their breeding and chick-rearing when insects (food) are abundant. Due to climate vagaries, either the birds are arriving early or late, thus missing the period when food is most abundant.

Many migratory birds have to fly 500–1000 km further to reach their prime breeding habitat in the Arctic and sub-Arctic as climate change has shifted the suitable habitat. With delicate energy balance, many individuals cannot migrate to the breeding habitat or are too exhausted to breed successfully when they cover the extra miles!

Not all bird species are going to suffer from climate change; some apparently will benefit as more habitats will be created for them. But, most birds will suffer in the short run, or in the long run. Sometimes suitable habitats are created and expanded in the short run, but climate and habitat modelling show that in the long run, say 50–100 years, the impact will be catastrophic. For example, the black-necked crane (*Grus nigricollis*) breeds in the high-altitude wetlands in Ladakh and the Tibetan plateau. These wetlands are mostly fed by glacial melts in summer as the rainfall is meager. Due to the increase in temperature, there is a huge increase in the melting of snow (some glaciers are extinct), resulting in an increase in the wetland areas, benefitting the black-necked cranes and other wetland-dependent species, but when the glaciers are gone, the wetlands will also disappear. Many wetlands in Tibet and Ladakh are already drying up due to climate change and rising temperatures. Despite the development of various infrastructure projects in Tibet, we are seeing an increase in the number of black-necked cranes, but in another 50–100 years, their populations will decrease when the wetlands dry up.

Meltofte et al. (2007) say “Climatic amelioration may benefit Arctic shorebirds in the short term by increasing both survival and productivity, whereas in the long-term habitat changes both on the breeding grounds and in the temperate and tropical non-breeding areas may put them under considerable pressure and may bring some of them near to extinction.” Many of these Arctic breeding species winter in India and we have already seen a huge decline in curlew sandpiper (*Calidris ferruginea*), dunlin (*Calidris alpina*), red knot (*Calidris canutus*), and other similar waders (S. Balachandran, *pers. comm.* 2020).

The impact of climate change is particularly noticeable in the mountains where many bird species live in a particular altitudinal band. If we take the example of pheasants, the blood pheasant (*Ithaginis cruentus*) lives between 3600 m and 4700 m (in winter as low as 1500 m), satyr tragopan (*Tragopan satyra*) is found between 2400 m and 3200 m, while Himalayan monal (*Lophophorus impejanus*) is found from 2600 m to 5000 m. Climate change is likely to shift their altitudinal range where they may not find suitable habitat left due to anthropogenic activities.

The Protected Area Network in India covers less than 5% of the land surface, unevenly distributed. The Himalayas are not particularly well represented in the PA system and do not cover all habitats and ecosystems properly. In the Himalayas, breeding and wintering areas of many species are different, sometimes just a few hundred meters above or below their breeding range. In a multi-institution and multi-country study in which the author also participated, covering the Eastern Himalayas and Lower Mekong, taking the distribution of nearly 350 bird species, it was shown that, by the year 2100, 45% of species studied will face declines in the availability of suitable climate within the network of Important Bird and Biodiversity Areas (IBAs), whereas increases were projected for only 2% of the species. While climate change will substantially alter the distribution of suitable climates for many species, the existing conservation site network has the potential to continue protecting species of conservation concern (Bagchi et al. 2013).

9.4.5 Plastic Pollution

Since the mass production of plastic in the 1950s, within a few decades, people started realizing its harmful effect. Even if only 90% of the plastic is recycled (in developed countries), the remaining 10% add incrementally to our environment. The main problem with plastic is its persistence or non-degradation through the natural ecological processes. The longevity of plastic is estimated to be hundreds to thousands of years but is likely to be far longer in deep-sea and non-surface polar environments (Barnes et al. 2009). Plastic debris in the water may even transport persistent organic pollutants (POPs) (Mato et al. 2001). Plastic debris is now found from urban waterways to the shores of the remotest islands, even in parts of Antarctica. It is not only the ugliness of plastic litter but also its disintegration into micro-plastic that is ingested by aquatic animals and accumulates in their body and goes up the food chain. We still do not know much about the impact of this microscopic plastic debris. This is a good topic for research.

Plastic has become a major threat to many birds, particularly seabirds which mistakenly feed on pieces of free-floating plastic thinking it is a food item. Plastic pollution in the ocean is a global concern; concentrations reach 580,000 pieces per km^2 and production is increasing exponentially (Wilcox et al. 2015). Seabirds are particularly vulnerable to plastic pollution and are widely observed to ingest floating plastic. Wilcox et al. (2015) have shown that, based on a literature survey, between 1962 and 2012, 80 of 135 (59%) species that were studied had ingested plastic, and, within those studies, on average, 29% of individuals had plastic in their gut. They also predict that plastic ingestion is increasing in seabirds, and it will reach 99% of all species by 2050. However, effective waste management can reduce this threat.

A recent review for the United Nations Convention on Biological Diversity documented over 600 species, ranging from microorganisms to whales, affected by marine plastic waste, largely through ingestion (Anonymous 2012).

Micro-plastic in the form of small pieces is engulfed by many filter-feeding fish and marine mammals. Micro-plastic is now recognized as an increasing threat to freshwater lakes and ponds (Fisher et al. 2016). Large pieces of plastic that now are found in and around lakes are broken down into smaller pieces and finally into micro-plastic. This micro-plastic mixes up with organic contents of the water and also in the soil. Quantity, quality, and distribution of micro-plastic depend on plastic pollution, wave action, soil grain size, temperature, and other chemicals found in a waterbody.

During a study on the sarus crane (*Grus antigone*) in seven districts of Uttar Pradesh, most of the wetlands that we surveyed were littered with discarded plastic (Rahmani et al. 2019). A recent study on the feeding habits of the black-necked crane (*Grus nigricollis*) in Bhutan revealed plastic in 5% of faeces ($n = 1000$ faeces samples). Samples were collected in Bumdeling, one of the major wintering grounds for the black-necked crane in Bhutan. Bumdeling is a small village of fewer than 3000 people so unlikely to have much plastic waste. Bhutan has officially banned one-time use of plastic carry bags and where the environment is still considered "pristine." Despite this, cranes are picking up plastic pieces thinking them to be food items. Contrast this with rural Uttar Pradesh where plastic is littered everywhere. Plastic has been regularly reported in the dung of elephants in many protected areas.

Not much work has been done in India on the impact of plastic on wildlife. Therefore, this is another new field for research and conservation action.

9.4.6 Pesticides

The classical book *Silent Spring* by Dr. Rachel Carson, first published in 1962, has highlighted the impact of pesticides, weedicides, and other chemicals on non-target species. Since then, there are hundreds of studies on the harmful impact of pesticides on birds, resulting in the ban or restricted use of many chemicals, once considered as beneficial. In India, some studies were sponsored on the impact of pesticides on birds by the DST, IARI, and CSIR, but there is no dedicated government institute on this subject. The Salim Ali Centre for Ornithology and Natural History (SACON) based at Coimbatore has been studying this topic since its establishment in 1992 (Murlidharan 2012).

In India, the manufacture of pesticides started soon after Independence, in 1952 to be exact. However, the import of DDT started in 1948 as a miracle chemical for the control of malaria. Benzene hexachloride (BHC) was also imported by India for control of locusts. By 1952, India started production of these chemicals. Boost for heavy use of pesticides was given during the Green Revolution in the 1960s. India is now the second largest consumer of pesticides in Asia, after China, and ranks 12th in the world. Persistence organophosphorus pesticides or POPs are now found in the general environment, impacting both humans and wildlife. Nearly 70% of the pesticides used in India are on cotton (45%) and paddy (22%) (Vyas 1998). Mukherjee et al. (Mukerjee et al. 2006) conducted studies on the use of pesticides in Gujarat and found that economically sound farmers with large landholdings use more pesticides than the traditional small farmers. The Economic characteristics of the farmers play an important role in the selection and quantum of pesticides used. In the terai, we have seen a similar situation where heavy use of pesticides was seen in large farms; however, we do not have quantitative data.

Wetlands are very susceptible to chemical pollution (pesticides, weedicides, fertilizers, fungicides, and industrial chemicals) (Varagiya et al. 2015; Muralidharan et al. 2014). Agriculture fields about wetlands and chemical runoff are very common.

Sarus frequently nests in paddy fields where heavy doses of pesticides are used. Hence, wetlands become a source of bioaccumulation and biomagnification of toxic chemicals and may reach birds through the food chain. The famous *jheels* of Keoladeo National Park, Bharatpur, receive run-off water from a large catchment area that is under intense agriculture. The water that comes to Keoladeo is contaminated by aldrin and BHC. Aldrin is suspected to be the main reason for the decline of sarus population in Keoladeo National Park (Muralidharan 1993; Muralidharan 2000). From a population of 27–30 breeding pairs in the 1970s, now not more than 2–3 pairs breed in the Park although there is no decrease in the *jheel* area.

A notorious case of chemical poisoning occurred outside Keoladeo National Park, Bharatpur, Rajasthan, on 23 November 2000, when 15 sarus cranes (*Grus antigone*) and 3 common cranes (*Grus grus*) were found dead in a field adjacent to the Park, where the wheat seed had been sown the previous day (Murlidharan 2004).

Besides the direct poisoning of birds by pesticides as seen in many cases of dead sarus (Muralidharan 1992; Kaur and Nair 2008), a more indirect impact is the disappearance of insects, resulting in scarcity of food for insectivorous birds. A recently released report of *State of India's Birds: Range, Trends and Conservation Status* (SoIB 2020) shows that, among the five diet guilds (plant-seed, omnivorous, fruit-nectar, invertebrate, and carnivorous eaters), in invertebrate (insects mainly) eaters, there is strong to moderate decline in the 98 species that were analyzed. The second greatest decline is seen in carnivorous birds, possibly due to multiple reasons, but biomagnification of chemicals could be one of the major reasons for these birds which are at the apex of the food chain.

During our surveys, in 2 years, we were thrice told by villagers that some sarus died after foraging in crop fields where pesticides have been used. We did not come across any dead sarus (it is not easy to find carcasses of dead wild animals as they are quickly eaten up by scavengers) but were told in Lakhimpur-Kheri districts that, a few years ago, eight sarus had died and the Forest Department was informed.

9.4.7 Sand Mining

Another conservation issue that has not come to the attention of most conservationists and on which very little research has been done in India is sand mining. The term "sand mining" includes the extraction of sand, pebbles, and gravel from rivers, lakes, and coasts. Sand and gravel are collectively called "aggregate." This aggregate is used to make concrete, for road construction, for mixing with asphalt, as construction fill, and in the production of construction materials like concrete blocks, bricks, and pipes.

The ecological, environmental, and social impact of sand mining is a complex issue with no one simple cause-effect model applicable to all systems (Koehnken et al. 2020). Koehnken et al. concluded "Channel incision is the most common physical change, but other responses are highly variable and linked to the inherent characteristics of the river system and other stressors. Collectively, the findings link sand mining to many changes in ecological structure, processes, and biodiversity of freshwater systems, including habitat loss and degradation, reduction and changes to the diversity and abundance of macroinvertebrate and fish populations, increased viability of invasive species, changes to food web dynamics, reductions in water quality and groundwater levels, and alterations to riparian processes."

According to the UNEP report (2014), a conservative estimate for the world consumption of aggregates exceeds 40 billion tons a year. This is twice the yearly amount of sediment carried by all of the rivers of the world (Milliman and Syvitski 1992), making humankind the largest of the planet's transforming agents with respect to aggregates. All this extraction, transportation, and use of cement in infrastructure development have environmental costs in the form of biodiversity loss, increase in water turbidity, decrease or increase in water table levels, and defacement of the landscape. There are other consequences in the form of land-use changes, exacerbation of flood impacts, and damage to bridges, river embankments, and coastal infrastructures. The price of illegal sand mining is paid by local communities as they do not benefit from resource extraction from their area. The infrastructures that are built with cement (the main aim of extracting aggregates) are generally very far and used by totally different people.

The impact of sand mining and pebble extraction is felt by riverine breeding reptiles such as gharial, mugger, and turtles and birds such as Indian skimmer, terns, pratincoles, lapwings, and waders (Koehnken and Rintoul 2018). While extraction of sand from rivers and beaches is now almost negligible in developed countries, it is an increasing problem in most developing countries. Despite good regulations, illegal sand mining is a huge problem in India. For example, in the linear 420 km long Chambal Gharial Sanctuary, straddling in three states (Rajasthan, Madhya Pradesh, and Uttar Pradesh), illegal sand mining is rampant. Besides the direct impact of the destruction of nests of reptiles and birds, the indirect impact of human presence, movement of trucks and tractor-trailers, human settlements, dogs, and crows further increase the predation chances of eggs and chicks. The birds abandon areas of heavy disturbances.

In India, bird species that are most impacted by sand mining activities are great thick-knee (*Esacus recurvirostris*), small pratincole (*Glareola lacteal*), Oriental pratincole (*Glareola maldivarum*), river lapwing (*Vanellus duvaucelii*), little ringed plover (*Charadrius dubius*), black-bellied tern (*Sterna acuticauda*), river tern (*Sterna aurantia*), and Indian skimmer (*Rynchops albicollis*). The main reasons for the decline of these birds appear to be sand mining and other human-related disturbances (Rahmani 2012).

BNHS and WII have started a project to study the impact of sand mining on the breeding of riverine birds. The impact of sand mining is a topic on which little research has to be done on a much larger scale in India. As the production of cement is necessary for the development of India, we need to know how much sand can be extracted sustainably from a particular river per year, in which season, and how the impact can be minimized on biodiversity and the quality of water. In the long term, we have to develop an alternative to natural sand or aggregate, recycle concrete, and develop new construction materials.

9.5 Conclusion

Indian birds, like a bird all over the world, are facing many new emerging threats to their survival. A recent study in North America (Rosenberg et al. 2019) has shown that more than a quarter of birds has disappeared in the last 50 years, a total of more than 3 billion birds. Comparative figures are not available for India but the decline could not be less. *eBirds* assessed the status of 867 Indian birds. Of the 261 species for which long-term trends could be determined, 52% have declined since the year 2000, with 22% declining strongly (SoIB 2020).

In order to develop conservation strategies, regulate the placement of infrastructures, determine mitigatory measures, and develop environment-friendly technology and regulatory mechanisms, we need better information on the ecological requirements of affected species, their movement and dispersal, long-term population trends, and their behavioural adaptations. There is a huge scope for university students to take up such studies. As the emerging threats, there is an emerging scope for research on new topics such as the impact of sand mining on riverine nesting birds; the value of maintaining natural habitats such as forests, grasslands, wetlands, mangrove, and mudflats for climate change mitigation; developing newer pesticides that have less impact on non-target species; technological improvement in generating and transmission of electricity with a minimum negative impact on birds and bats; controlling the population of free-ranging dogs; etc. The scope is endless. Funding organizations such as CSIR and DST should encourage research on new emerging topics of conservation concern.

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Chapter 10
Status, Issues, and Challenges of Indian Livestock Biodiversity

Sonika Ahlawat and Rekha Sharma

10.1 Introduction

India is bestowed with diverse livestock and poultry species contributing toward the livelihood and nutritional security of its large population. The spectrum of biodiversity is exceedingly vast and varied. The presence of more than 197 breeds of various livestock species and poultry is unparalleled worldwide, both in variety and variability in terms of breeds, populations, and unique genotypes. These farm animal genetic resources (AnGR) have remained the backbone of the Indian agrarian economy through the production of milk, meat, eggs, fibers, and manure. The livestock sector is an integral part of Indian agriculture and has never shown negative growth during the last four decades. It has continuously played a major role in enhancing farmers' income, sustainable rural development, and nutritional security to the burgeoning population and provides ample opportunities for entrepreneurial growth. The distribution of AnGR in India is more egalitarian, compared to land. Hence, from the equity and livelihood perspectives, it is considered an important component in poverty alleviation programs.

More recently, modern breeders have applied the science of genetics and breeding to produce more efficient, high-producing farm animals mainly through crossbreeding with exotic germplasm. In the process, the populations and genetic base of several valuable indigenous breeds and strains of animals are shrinking rapidly. In addition, the problem of shrinking landholdings, grazing resources, scarcity of water, climate change, the declining interest of new generation for livestock rearing, migration activity, poor health-care support, unorganized marketing structure, ineffective financial support, and poor risk management strategies are leading toward apathy. In the changing socio-economic scenario, it is becoming increasingly

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difficult to save local breeds, especially those which are low-producing. The changing scenario calls for breeds with high performance to have higher profits. Sustaining low-producing local breeds with poor economic viability is therefore really a challenge (FAO 2020). The use of a few specialized breeds with optimized specific production traits has led to a narrowing of the genetic base, as native breeds and species are neglected in response to market forces. Declining livestock diversity may have adverse effects on our capacity to mitigate the enormous challenges posed by climate change and emerging diseases. We may need to rely back on the adaptability and potential of indigenous animal genetic resources to face an uncertain future. We need to consider the conservation of farm animal genetic resources as insurance that our generation and future generations have a healthy and adequate food supply.

10.2 Status in Terms of Number and Diversity Indices

Genetic diversity defines not only animal breeds' production and functional traits but also their ability to adapt to different environments, including food and water availability, climate, pests, and diseases. Diverse animal genetic resources are a key to economic development. Many local livestock breeds continue to represent the lifeline of rural populations. The diversity of these resources makes possible human livelihoods in some of the most inhospitable areas where crop production cannot be exclusively relied upon. While they may not be able to compete with "improved breeds" in milk and meat yields, they fulfill a much wider range of functions and provide a larger range of products. Owing to their ability to thrive even with low fodder inputs, their maintenance is ecologically more sustainable, especially in marginal environments. Requiring lower levels of health care and management, they commonly entail a lower workload in comparison with exotic breeds. As is becoming increasingly clear, they often have scope for speciality products and can be essential to preserve habitats and cultures. At the local level, the loss of a breed means the loss of a livelihood strategy and loss of indigenous knowledge. It also emphasizes the need for the active involvement of indigenous communities and the role of local knowledge and institutions in conservation.

Indian livestock and poultry population is 535.78 and 851.81 million, respectively. The major species of Indian livestock include cattle (35.94%), buffalo (20.45%), goat (27.8%), sheep (13.87%), pigs (1.69%), and others (0.23%). The livestock wealth of India and the population trend over the last three censuses have been presented in Table 10.1. Avian species include 807.89 million fowls, 33.51 million ducks, 10.41 million turkeys, and other poultry (Livestock Census 2019). The country possesses the maximum number of buffalo in the world and the second-largest population of cattle and goats. It ranks third in sheep, fourth in duck, fifth in poultry, and sixth in camel population of the world. Farmers of marginal, small, and semi-medium operational holdings (area less than 4 hectares) own about 87.7% of the livestock (Livestock Census 2019). The comparative value of Indian livestock in millions as of 2019 is given in Fig. 10.1

Table 10.1 Livestock population (in million) of major species in India (2007–2019)

Category	Population, 2007	Population, 2012	Population, 2019	Change (2012–2019) (%)
Cattle	199.08	190.90	192.49	0.83
Buffalo	105.34	108.70	109.85	1.06
Sheep	71.56	65.07	74.26	14.13
Goat	14.054	135.17	148.88	10.14
Pig	11.13	10.29	9.06	−12.03
Mithun	0.26	0.30	0.38	26.66
Yak	0.08	0.08	0.06	−25.00
Horses and ponies	0.61	0.63	0.34	−45.58
Mule	0.14	0.20	0.08	−57.09
Donkey	0.44	0.32	0.12	−61.23
Camel	0.52	0.40	0.25	−37.05
Total	529.70	512.06	535.78	4.63

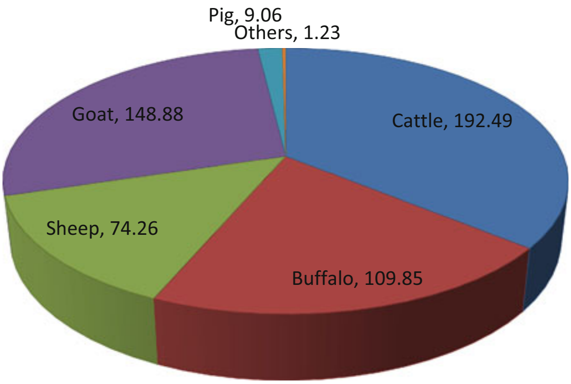

Fig. 10.1 Population (million) of Indian livestock

The advent of a new era of national sovereignty over genetic resources under the Convention on Biological Diversity (CBD) requires a new approach to describe and catalogue livestock and poultry breeds. According to the Trade-Related Aspects of Intellectual Property Rights (TRIPS) under the General Agreement on Tariff and Trade (GATT) of the World Trade Organization (WTO) through Article 27, "patents shall be available for any invention." It implies member countries to provide protection to their livestock and poultry genetic resources by an effective sui generis system. This in turn demands an authentic national documentation system of valuable sovereign genetic resources with well-defined characteristics. Toward this end, a mechanism for "Registration of Animal Germplasm" is being initiated by the Indian Council of Agricultural Research (ICAR) at the National Bureau of Animal Genetic Resources (ICAR-NBAGR), Karnal (ICAR 2020). This would provide identity and protection to the valuable animal genetic resources and facilitate their access to genetic improvement and economic utilization. The registration of Indian

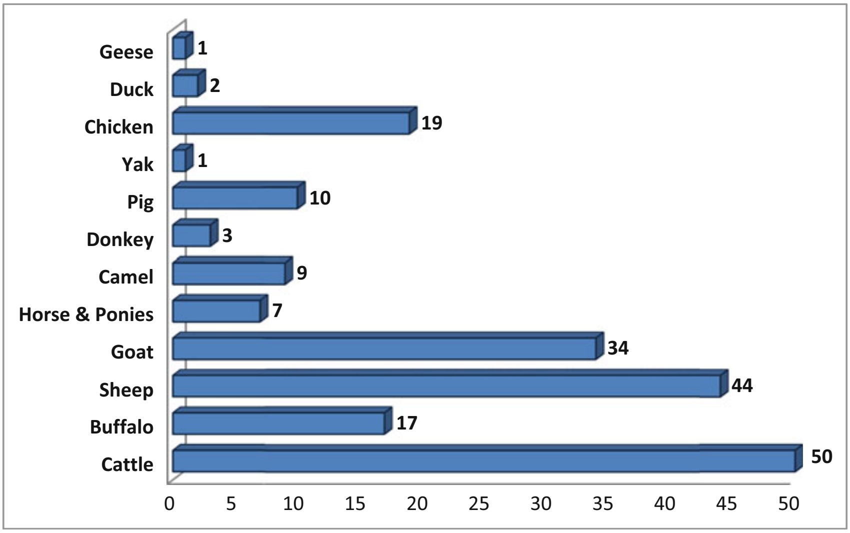

Fig. 10.2 Registered breeds of indigenous livestock and poultry

livestock and poultry germplasm shall revolve around the concept of a breed. It is difficult to exactly define a breed; however, FAO has defined the breed (FAO 2007) which is widely accepted, as follows:

The breeds are

1. Either a sub-specific group of domestic livestock with definable and identifiable external characteristics that enable it to be separated by a visual appraisal from other similarly defined groups within the same species.
2. Or a group for which geographical and/or cultural separation from phenotypically similar groups has led to the acceptance of its separate identity.

There are 197 registered breeds comprising 50 cattle, 17 buffalo, 44 sheep, 34 goat, 7 horses and ponies, 9 camel, 3 donkey, 10 pig, 19 chicken, 2 duck, and 1 each of yak and geese (Fig. 10.2 & Table 10.2). All these breeds have been developed over centuries by natural and manmade selection to meet the specific needs as per production systems and native environments. The defined breeds have become prominent during the last two decades with various activities and effective awareness generation by ICAR-NBAGR. More and more populations in the country are now being characterized and registered as breeds. The proportion of non-descript animals in each species is decreasing steadily, and purity within breeds is also increasing. Organizations/departments/universities seeking to get their unique livestock and poultry populations registered as breeds may apply in the prescribed format to Director, NBAGR, P.O. Box 129, Karnal—132001 (https://nbagr.icar.gov.in/).

Table 10.2 List of breeds and their accession numbers for livestock and poultry of India

S.N.	Breed	Home tract	Accession number
1. Cattle			
1.	Amritmahal	Karnataka	INDIA_CATTLE_0800_AMRITMAHAL_03001
2.	Bachaur	Bihar	INDIA_CATTLE_0300_BACHAUR_03002
3.	Bargur	Tamil Nadu	INDIA_CATTLE_1800_BARGUR_03003
4.	Dangi	Maharashtra and Gujarat	INDIA_CATTLE_1104_DANGI_03004
5.	Deoni	Maharashtra and Karnataka	INDIA_CATTLE_1108_DEONI_03005
6.	Gaolao	Maharashtra and Madhya Pradesh	INDIA_CATTLE_1110_GAOLAO_03006
7.	Gir	Gujarat	INDIA_CATTLE_0400_GIR_03007
8.	Hallikar	Karnataka	INDIA_CATTLE_0800_HALLIKAR_03008
9.	Hariana	Haryana, Uttar Pradesh and Rajasthan	INDIA_CATTLE_0520_HARIANA_03009
10.	Kangayam	Tamil Nadu	INDIA_CATTLE_1800_KANGAYAM_03010
11.	Kankrej	Gujarat and Rajasthan	INDIA_CATTLE_0417_KANKREJ_03011
12.	Kenkatha	Uttar Pradesh and Madhya Pradesh	INDIA_CATTLE_2010_KENKATHA_03012
13.	Kherigarh	Uttar Pradesh	INDIA_CATTLE_2000_KHERIGARH_03013
14.	Khillar	Maharashtra and Karnataka	INDIA_CATTLE_1108_KHILLAR_03014
15.	Krishna Valley	Karnataka	INDIA_CATTLE_0800_KRISHNAVALLEY_03015
16.	Malvi	Madhya Pradesh	INDIA_CATTLE_1000_MALVI_03016
17.	Mewati	Rajasthan, Haryana and Uttar Pradesh	INDIA_CATTLE_1705_MEWATI_03017
18.	Nagori	Rajasthan	INDIA_CATTLE_1700_NAGORI_03018
19.	Nimari	Madhya Pradesh	INDIA_CATTLE_1000_NIMARI_03019
20.	Ongole	Andhra Pradesh	INDIA_CATTLE_0100_ONGOLE_03020
21.	Ponwar	Uttar Pradesh	INDIA_CATTLE_2000_PONWAR_03021
22.	Punganur	Andhra Pradesh	INDIA_CATTLE_0100_PUNGANUR_03022
23.	Rathi	Rajasthan	INDIA_CATTLE_1700_RATHI_03023
24.	Red Kandhari	Maharashtra	INDIA_CATTLE_1100_REDKANDHARI_03024

(continued)

Table 10.2 (continued)

S.N.	Breed	Home tract	Accession number
25.	Red Sindhi	On organized farms only	INDIA_CATTLE_0000_REDSINDHI_03025
26.	Sahiwal	Punjab and Rajasthan	INDIA_CATTLE_1617_SAHIWAL_03026
27.	Siri	Sikkim and West Bengal	INDIA_CATTLE_2221_SIRI_03027
28.	Tharparkar	Rajasthan	INDIA_CATTLE_1700_THARPARKAR_03028
29.	Umblachery	Tamil Nadu	INDIA_CATTLE_1800_UMBLACHERY_03029
30.	Vechur	Kerala	INDIA_CATTLE_0900_VECHUR_03030
31.	Motu	Odisha, Chhattisgarh, and Andhra Pradesh	INDIA_CATTLE_1526_MOTU_03031
32.	Ghumusari	Odisha	INDIA_CATTLE_1500_GHUMUSARI_03032
33.	Binjharpuri	Odisha	INDIA_CATTLE_1500_BINJHARPURI_03033
34.	Khariar	Odisha	INDIA_CATTLE_1500_KHARIAR_03034
35.	Pulikulam	Tamil Nadu	INDIA_CATTLE_1800_PULIKULAM_03035
36.	Kosali	Chhattisgarh	INDIA_CATTLE_2600_KOSALI_03036
37.	Malnad Gidda	Karnataka	INDIA_CATTLE_0800_MALNADGIDDA_03037
38.	Belahi	Haryana and Chandigarh	INDIA_CATTLE_0532_BELAHI_03038
39.	Gangatiri	Uttar Pradesh and Bihar	INDIA_CATTLE_2003_GANGATIRI_03039
40.	Badri	Uttarakhand	INDIA_CATTLE_2400_BADRI_03040
41.	Lakhimi	Assam	INDIA_CATTLE_0200_LAKHIMI_03041
42.	Ladakhi	Jammu and Kashmir (J & K)	INDIA_CATTLE_0700_LADAKHI_03042
43.	Konkan Kapila	Maharashtra and Goa	INDIA_CATTLE_1135_KONKANKAPILA_03043
44.	Poda Thurpu	Telangana	INDIA_CATTLE_3600_PODATHURPU_03044
45.	Nari	Rajasthan and Gujarat	INDIA_CATTLE_1704_NARI_03045
46.	Dagri	Gujarat	INDIA_CATTLE_0400_DAGRI_03046
47.	Thutho	Nagaland	INDIA_CATTLE_1400_THUTHO_03047
48.	Shweta Kapila	Goa	INDIA_CATTLE_3500_SHWETAKAPILA_03048
49.	Himachali Pahari	Himachal Pradesh	INDIA_CATTLE_0600_HIMACHALIPAHARI_03049

50.	Purnea	Bihar	INDIA_CATTLE_0300_PURNEA_03050
2. Buffalo			
1.	Bhadawari	Uttar Pradesh and Madhya Pradesh	INDIA_BUFFALO_2010_BHADAWARI_01003
2.	Jaffarabadi	Gujarat	INDIA_BUFFALO_0400_JAFFARABADI_01006
3.	Marathwadi	Maharashtra	INDIA_BUFFALO_1100_MARATHWADI_01009
4.	Mehsana	Gujarat	INDIA_BUFFALO_0400_MEHSANA_01004
5.	Murrah	Haryana	INDIA_BUFFALO_0500_MURRAH_01001
6.	Nagpuri	Maharashtra	INDIA_BUFFALO_1100_NAGPURI_01007
7.	Nili-Ravi	Punjab	INDIA_BUFFALO_1600_NILIRAVI_01002
8.	Pandharpuri	Maharashtra	INDIA_BUFFALO_1100_PANDHARPURI_01008
9.	Surti	Gujarat	INDIA_BUFFALO_0400_SURTI_01005
10.	Toda	Tamil Nadu	INDIA_BUFFALO_0018_TODA_01010
11.	Banni	Gujarat	INDIA_BUFFALO_0400_BANNI_01011
12.	Chilika	Odisha	INDIA_BUFFALO_1500_CHILIKA_01012
13.	Kalahandi	Odisha	INDIA_BUFFALO_1500_KALAHANDI_01013
14.	Luit (Swamp)	Assam and Manipur	INDIA_BUFFALO_0212_LUIT_01014
15.	Bargur	Tamil Nadu	INDIA_BUFFALO_1800_BARGUR_01015
16.	Chhattisgarhi	Chhattisgarh	INDIA_BUFFALO_2600_CHHATTISGARHI_01016
17.	Gojri	Punjab and Himachal Pradesh	INDIA_BUFFALO_1606_GOJRI_01017
3. Goat			
1.	Attappady Black	Kerala	INDIA_GOAT_0900_ATTAPADYBLACK_06001
2.	Barbari	Uttar Pradesh and Rajasthan	INDIA_GOAT_2017_BARBARI_06002
3.	Beetal	Punjab	INDIA_GOAT_1600_BEETAL_06003
4.	Black Bengal	West Bengal	INDIA_GOAT_2100_BLACKBENGAL_06004
5.	Changthangi	Jammu and Kashmir	INDIA_GOAT_0700_CHANGTHANGI_06005
6.	Chegu	Himachal Pradesh	INDIA_GOAT_0600_CHEGU_06006
7.	Gaddi	Himachal Pradesh	INDIA_GOAT_0600_GADDI_06007

(continued)

Table 10.2 (continued)

S.N.	Breed	Home tract	Accession number
8.	Ganjam	Odisha	INDIA_GOAT_1500_GANJAM_06008
9.	Gohilwadi	Gujarat	INDIA_GOAT_0400_GOHILWADI_06009
10.	Jakhrana	Rajasthan	INDIA_GOAT_1700_JAKHRANA_06010
11.	Jamunapari	Uttar Pradesh	INDIA_GOAT_2000_JAMUNAPARI_06011
12.	Kanni Adu	Tamil Nadu	INDIA_GOAT_1800_KANNIADU_06012
13.	Kutchi	Gujarat	INDIA_GOAT_0400_KUTCHI_06013
14.	Malabari	Kerala	INDIA_GOAT_0900_MALABARI_06014
15.	Marwari	Rajasthan	INDIA_GOAT_1700_MARWARI_06015
16.	Mehsana	Gujarat	INDIA_GOAT_0400_MEHSANA_06016
17.	Osmanabadi	Maharashtra	INDIA_GOAT_1100_OSMANABADI_06017
18.	Sangamneri	Maharashtra	INDIA_GOAT_1100_SANGAMNERI_06018
19.	Sirohi	Rajasthan and Gujarat	INDIA_GOAT_1704_SIROHI_06019
20.	Surti	Gujarat	INDIA_GOAT_0400_SURTI_06020
21.	Zalawadi	Gujarat	INDIA_GOAT_0400_ZALAWADI_06021
22.	Konkan Kanyal	Maharashtra	INDIA_GOAT_1100_KONKANKANYAL_06022
23.	Berari	Maharashtra	INDIA_GOAT_1100_BERARI_06023
24.	Pantja	Uttarakhand and Uttar Pradesh	INDIA_GOAT_2420_PANTJA_06024
25.	Teressa	Andaman and Nicobar	INDIA_GOAT_3300_TERESSA_06025
26.	Kodi Adu	Tamil Nadu	INDIA_GOAT_1800_KODIADU_06026
27.	Salem Black	Tamil Nadu	INDIA_GOAT_1800_SALEMBLACK_06027
28.	Sumi-Ne	Nagaland	INDIA_GOAT_1400_SUMINE_06028
29.	Kahmi	Gujarat	INDIA_GOAT_0400_KAHMI_06029
30.	Rohilkhandi	Uttar Pradesh	INDIA_GOAT_2000_ ROHILKHANDI _06030
31.	Assam Hill	Assam and Meghalaya	INDIA_GOAT_0213_ ASSAMHILL _06031
32.	Bidri	Karnataka	INDIA_GOAT_0800_ BIDRI _06032

33.	Nandidurga	Karnataka	INDIA_GOAT_0800_ NANDIDURGA _06033
34.	Bhakarwali	Jammu and Kashmir	INDIA_GOAT_0700_ BHAKARWALI _06034
4. Sheep			
1.	Balangir	Odisha	INDIA_SHEEP_1500_BALANGIR_14033
2.	Bellary	Karnataka	INDIA_SHEEP_0800_BELLARY_14019
3.	Bakharwal	Jammu and Kashmir	INDIA_SHEEP_0700_BHAKARWAL_14001
4.	Bonpala	Sikkim	INDIA_SHEEP_2200_BONPALA_14034
5.	Changthangi	Jammu and Kashmir	INDIA_SHEEP_0700_CHANGTHANGI_14002
6.	Chokla	Rajasthan	INDIA_SHEEP_1700_CHOKLA_14008
7.	Chottanagpuri	Jharkhand	INDIA_SHEEP_2500_CHOTTANAGPURI_14035
8.	Coimbatore	Tamil Nadu	INDIA_SHEEP_1800_COIMBATORE_14020
9.	Deccani	Andhra Pradesh and Maharashtra	INDIA_SHEEP_0111_DECCANI_14021
10.	Gaddi	Himachal Pradesh	INDIA_SHEEP_0600_GADDI_14003
11.	Ganjam	Odisha	INDIA_SHEEP_1500_GANJAM_14036
12.	Garole	West Bengal	INDIA_SHEEP_2100_GAROLE_14039
13.	Gurez	Jammu and Kashmir	INDIA_SHEEP_0700_GUREZ_14004
14.	Hassan	Karnataka	INDIA_SHEEP_0800_HASSAN_14022
15.	Jaisalmeri	Rajasthan	INDIA_SHEEP_1700_JAISALMERI_14009
16.	Jalauni	Uttar Pradesh and Madhya Pradesh	INDIA_SHEEP_2010_JALAUNI_14010
17.	Karnah	Jammu and Kashmir	INDIA_SHEEP_0700_KARNAH_14005
18.	Kenguri	Karnataka	INDIA_SHEEP_0800_KENGURI_14023
19.	Kilakarsal	Tamil Nadu	INDIA_SHEEP_1800_KILAKARSAL_14024
20.	Madras Red	Tamil Nadu	INDIA_SHEEP_1800_MADRASRED_14025
21.	Magra	Rajasthan	INDIA_SHEEP_1700_MAGRA_14011
22.	Malpura	Rajasthan	INDIA_SHEEP_1700_MALPURA_14012
23.	Mandya	Karnataka	INDIA_SHEEP_0800_MANDYA_14026
24.	Marwari	Rajasthan and Gujarat	INDIA_SHEEP_1704_MARWARI_14013

(continued)

Table 10.2 (continued)

S.N.	Breed	Home tract	Accession number
25.	Mecheri	Tamil Nadu	INDIA_SHEEP_1800_MECHERI_14027
26.	Muzaffarnagari	Uttar Pradesh and Uttarakhand	INDIA_SHEEP_2024_MUZZAFARNAGRI_14014
27.	Nali	Rajasthan	INDIA_SHEEP_1700_NALI_14015
28.	Nellore	Andhra Pradesh	INDIA_SHEEP_0100_NELLORE_14028
29.	Nilgiri	Tamil Nadu	INDIA_SHEEP_1800_NILGIRI_14029
30.	Patanwadi	Gujarat	INDIA_SHEEP_0400_PATANWADI_14016
31.	Poonchi	Jammu and Kashmir	INDIA_SHEEP_0700_POONCHI_14006
32.	Pugal	Rajasthan	INDIA_SHEEP_1700_PUGAL_14017
33.	Ramnad White	Tamil Nadu	INDIA_SHEEP_1800_RAMNADWHITE_14030
34.	Rampur Bushair	Himachal Pradesh	INDIA_SHEEP_0600_RAMPURBUSHAIR_14007
35.	Shahabadi	Bihar	INDIA_SHEEP_0300_SHAHBADI_14037
36.	Sonadi	Rajasthan	INDIA_SHEEP_1700_SONADI_14018
37.	Tibetan	Arunachal Pradesh	INDIA_SHEEP_2300_TIBETAN_14038
38.	Tiruchy Black	Tamil Nadu	INDIA_SHEEP_1800_TIRUCHIBLACK_14031
39.	Vembur	Tamil Nadu	INDIA_SHEEP_1800_VEMBUR_14032
40.	Katchaikatty Black	Tamil Nadu	INDIA_SHEEP_1800_KATCHAIKATTYBLACK_14040
41.	Chevaadu	Tamil Nadu	INDIA_SHEEP_1800_CHEVAADU_14041
42.	Kendrapada	Odisha	INDIA_SHEEP_1500_KENDRAPADA_14042
43.	Panchali	Gujarat	INDIA_SHEEP_0400_PANCHALI_14043
44.	Kajali	Punjab	INDIA_SHEEP_1600_KAJALI_14044
5. Horse and Pony			
1.	Bhutia	Sikkim and Arunachal Pradesh	INDIA_HORSE_2223_BHUTIA_07005
2.	Kathiawari	Gujarat	INDIA_HORSE_0400_KATHIAWARI_07002
3.	Manipuri	Manipur	INDIA_HORSE_1200_MANIPURI_07003
4.	Marwari	Rajasthan	INDIA_HORSE_1700_MARWARI_07001

5.	Spiti	Himachal Pradesh	INDIA_HORSE_0600_SPITI_07004
6.	Zanskari	Jammu and Kashmir	INDIA_HORSE_0700_ZANSKARI_07006
7.	Kachchhi-Sindhi	Gujarat and Rajasthan	INDIA_HORSE_0417_KACHCHHISINDHI_07007
6. Camel			
1.	Bikaneri	Rajasthan	INDIA_CAMEL_1700_BIKANERI_02001
2.	Jaisalmeri	Rajasthan	INDIA_CAMEL_1700_JAISALMERI_02002
3.	Jalori	Rajasthan	INDIA_CAMEL_1700_JALORI_02004
4.	Kutchi	Gujarat	INDIA_CAMEL_0400_KUTCHI_02007
5.	Malvi	Madhya Pradesh	INDIA_CAMEL_1000_MALVI_02008
6.	Marwari	Rajasthan	INDIA_CAMEL_1700_MARWARI_02003
7.	Mewari	Rajasthan	INDIA_CAMEL_1700_MEWARI_02005
8.	Mewati	Rajasthan and Haryana	INDIA_CAMEL_1705_MEWATI_02006
9.	Kharai	Gujarat	INDIA_CAMEL_0400_KHARAI_02009
7. Pig			
1.	Ghungroo	West Bengal	INDIA_PIG_2100_GHOONGROO_09001
2.	Niang Megha	Meghalaya	INDIA_PIG_1300_NIANGMEGHA_09002
3.	Agonda Goan	Goa	INDIA_PIG_3500_AGONDAGOAN_09003
4.	Tenyi Vo	Nagaland	INDIA_PIG_1400_TENYIVO_09004
5.	Nicobari	Andaman and Nicobar	INDIA_PIG_3300_NICOBARI_09005
6.	Doom	Assam	INDIA_PIG_0200_DOOM_09006
7.	Zovawk	Mizoram	INDIA_PIG_2700_ZOVAWK_09007
8.	Ghurrah	Uttar Pradesh	INDIA_PIG_2000_GHURRAH_09008
9.	Mali	Tripura	INDIA_PIG_1900_MALI_09009
10.	Purnea	Bihar and Jharkhand	INDIA_PIG_0325_PURNEA_09010
8. Donkey			
1.	Spiti	Himachal Pradesh	INDIA_DONKEY_0600_SPITI_05001
2.	Halari	Gujarat	INDIA_DONKEY_0400_HALARI_05002
3.	Kachchhi	Gujarat	INDIA_DONKEY_0400_KACHCHHI_05003
9. Yak			

(continued)

Table 10.2 (continued)

S.N.	Breed	Home tract	Accession number
1.	Arunachali	Arunachal Pradesh	INDIA_YAK_2300_ARUNACHALI_16001
10. Chicken			
1.	Ankaleshwar	Gujarat	INDIA_CHICKEN_0400_ANKALESHWAR_12001
2.	Aseel	Chhattisgarh, Odisha, and Andhra Pradesh	INDIA_CHICKEN_2615_ASEEL_12002
3.	Busra	Gujarat and Maharashtra	INDIA_CHICKEN_0411_BUSRA_12003
4.	Chittagong	Meghalaya and Tripura	INDIA_CHICKEN_1319_CHITTAGONG_12004
5.	Danki	Andhra Pradesh	INDIA_CHICKEN_0100_DANKI_12005
6.	Daothigir	Assam	INDIA_CHICKEN_0200_DAOTHIGIR_12006
7.	Ghagus	Andhra Pradesh and Karnataka	INDIA_CHICKEN_0108_GHAGUS_12007
8.	Harringhata Black	West Bengal	INDIA_CHICKEN_2100_HARRINGHATABLACK_12008
9.	Kadaknath	Madhya Pradesh	INDIA_CHICKEN_1000_KADAKNATH_12009
10.	Kalasthi	Andhra Pradesh	INDIA_CHICKEN_0100_KALASTHI_12010
11.	Kashmir Favorolla	Jammu and Kashmir	INDIA_CHICKEN_0700_KASHMIRFAVOROLLA_12011
12.	Miri	Assam	INDIA_CHICKEN_0200_MIRI_12012
13.	Nicobari	Andaman and Nicobar	INDIA_CHICKEN_3300_NICOBARI_12013
14.	Punjab Brown	Punjab and Haryana	INDIA_CHICKEN_1605_PUNJABBROWN_12014
15.	Tellichery	Kerala	INDIA_CHICKEN_0900_TELLICHERY_12015
16.	Mewari	Rajasthan	INDIA_CHICKEN_1700_MEWARI_12016
17.	Kaunayen	Manipur	INDIA_CHICKEN_1200_KAUNAYEN_12017
18.	Hansli	Odisha	INDIA_CHICKEN_1500_HANSLI_12018
19.	Uttara	Uttarakhand	INDIA_CHICKEN_2400_ UTTARA_12019
11. Geese			
New Breeds			
1.	Kashmir Anz	Jammu and Kashmir	INDIA_GEESE_0700_KASHMIRANZ_18001
12. Duck			
1.	Pati	Assam	INDIA_DUCK_0200_PATI_11001
2.	Maithili	Bihar	INDIA_DUCK_0300_MAITHILI_11002

10.3 Reasons of Worry

The diminishing livestock genetic resources are not only associated with the extinction of indigenous breeds but also with the loss of within-breed genetic diversity as well as to loss of unique genes and gene combinations. Consequently, the capability of a breed to respond to selection for increasing productivity or for adjusting to altering environmental conditions, changes in markets, management and husbandry practices, and challenges imposed by disease is also gone. Livestock genetic diversity allows the sustainable existence of livestock in exceedingly marginal environments, where local livestock breeds are critical for sustaining rural livelihoods by providing a broad range of products with comparatively minimal input. The fall in numbers or complete loss of these locally accustomed AnGR also forces villagers to migrate to already congested cities leading to mounting food insecurity and social breakdown of rural communities. A negative impact on the yield of local crops is also expected as livestock and crop interaction is the characteristic of low-input production systems. Moreover, livestock provides vital non-monetary payback by enabling the deprived and landless populace to access and exploit common grazing areas, by providing organic fertilizer for cultivation, by carrying out rituals and religious and community exchange traditions, and by serving as any time bank account that can be cashed as and when required. Nevertheless, several breeds have gone forever and numerous are at risk of extinction. In real meaning, the loss of a registered breed is a loss of cultural identity for the stakeholder and a loss of precious human legacy. Hence, it is desired that the economic value of AnGR should encompass the direct and indirect role of the animals while compared to its counterparts. AnGR are also indispensable in research in reproduction, genetics, immunology, nutrition, and climate change.

10.4 Challenges

10.4.1 Increase in Demand for Livestock Products

Globally, the human population is expected to increase from 7.2 billion today to 9.6 billion by 2050 representing an increase of 33%. As the global standard of living improves, the demand for livestock products is likely to increase twofold during the first half of this century. India having the world's highest population growth will also be in a stiff position to meet the nutritional demand of its people. One can foresee the extreme challenges for the Indian livestock industry in the coming decades since the per capita consumption of livestock and poultry products (meat, milk, and eggs) is expected to increase substantially by 2050.

10.4.2 Poor Productivity of Indigenous Animals

India is the largest producer of milk in the world primarily due to the increase in the number of bovines in milk. The dairy enterprise is crippled by a huge population of cattle with low productivity. At present, the overall productivity of Indian milch animals is almost half of the world average of 2200 Kg/year. The highest growth of about 8% in milk production has been observed in crossbred cattle followed by about 4% in buffaloes. However, indigenous cattle recorded merely a 2% annual growth rate in milk production. The average yield of different categories of bovines is depicted in Table 10.3.

10.4.3 Scarcity of Feed and Fodder

Animal production systems are increasingly being confronted with the inadequacy of feed and fodder resources due to the dwindling pastures over the last few years. Estimates of the Standing Committee on Agriculture (2016–2017) pointed out that the deficit in requirement and the availability of green fodder, dry fodder, and concentrates for the year 2015 was to the tune of 26%, 21%, and 34%, respectively. In times to come, the fodder shortage is predicted to worsen by 2025 since only about 4% of the total cropped area is devoted to fodder production, against the actual requirement of 11%. The last four decades have not witnessed an increase in area under fodder cultivation. A point worth mentioning here is that the low productivity of indigenous animals can be directly attributed to the inadequate availability of feed and fodder. If the shortage continues, then sustaining livestock would become an insurmountable challenge and would completely derail the rural economy.

10.4.4 Declining Population Trends

The intensification of animal husbandry with few improver breeds has completely altered the scenario of native AnGR of the country. There is a perceptible increase in a limited number of specialized breeds, whereas a reduction has occurred in genetic variability and population size of many local breeds which failed to meet the increasing production requirements of the farming enterprise. Fading utility for

Table 10.3 Average yield per animal (2018–19)

Type of animal	Average yield (Kg/day)
Exotic cow	11.67
Cross-bred cow	7.85
Indigenous cow	3.85
Non-descript cow	2.50
Indigenous buffalo	6.34

Table 10.4 National Watch List

Vulnerable (6 breeds)	Endangered (13 breeds)	Critical (7 breeds)
Ponwar cattle (Uttar Pradesh)	Siri cattle (Sikkim and WB)	Vechur cattle (Kerala)
Mewati cattle (Rajasthan, UP and Haryana)	Krishna Valley cattle (Karnataka)	Kachaikatty Black sheep (Tamil Nadu)
Bargur cattle (Tamil Nadu)	Pulikulam cattle (Tamil Nadu)	Marwari camel (Rajasthan)
Gurez sheep (Jammu and Kashmir)	Punganur cattle (Andhra Pradesh)	Malvi camel (Rajasthan)
Teressa goat (Andaman and Nicobar)	Toda buffalo (Tamil Nadu)	Jalori camel (Rajasthan)
Kutchi camel (Gujarat)	Chilika buffalo (Odisha)	Spiti horse (Uttarakhand)
	Poonchi sheep (J & K)	Manipuri horse (Manipur)
	Karnah sheep (J & K)	
	Attappady Black goat (Kerala)	
	Kharai camel (Gujarat)	
	Zanskari horse (J & K)	
	Bhutia horse (Sikkim and Arunachal)	
	Doom pig (Assam)	

indigenous cattle draught breeds and low productivity of most of the breeds of indigenous cattle and buffalo have also remained two important causes for peoples' preferences for alternative germplasm or highly specialized breeds. Many populations of camel, horse, donkey, and yak utilized for transportation have declined significantly, and seemingly, most of them are under threat. As a result of these developments, several indigenous livestock and poultry breeds over the years have suffered decline and genetic erosion. Besides registered breeds, there are many unique non-descript populations that are encountering a greater threat of dilution of germplasm due to policies of crossbreeding or upgrading for genetic improvement. The introduction of exotic germplasm especially in cattle, chicken, pig, and sheep from agriculturally advanced economies has resulted in a serious erosion of highly adapted farm animals, possibly also threatening the composite sustainability of their livestock production systems. In a recent breed-wise livestock survey (2012), about 20% of the total indigenous livestock breeds in the country are at risk. The proportion of breeds under threat is much higher in minor species including camel and horses. Table 10.4 presents the list of breeds which are registering dwindling populations.

10.4.5 Large Proportion of Livestock and Poultry Diversity Is Uncharacterized

At present, there are 197 registered indigenous breeds of farm animals in India; however, FAO has predicted that there are 275 livestock breeds in the country. Looking at the worldwide scenario, there is one breed per million animals in the world in contrast to one breed per 3.5 million livestock population in India (0.28 breed/million). This means that there are many undefined populations that have not yet been characterized and deserve exploration. First indications about the population of the livestock that have been recognized as defined breeds are available from the 19th Livestock census and Breed Survey Report (2013). Going by Livestock Census (2019) data, about 54% of the livestock population is still non-descript in India which includes 60% cattle, 45%, 38% sheep, 62% goats, 73% pigs, and 44% equines/camels (Fig. 10.3).

10.4.6 Poor Implementation of Breeding Policies

Our country has a well-articulated breeding policy and programs for livestock improvement at the national level. Additionally, considering local needs and available genetic resources, each state has also devised its own breeding policy in accordance with the national guidelines. Unfortunately, different states lay more emphasis on crossbreeding, without due importance to improvement through selection in indigenous breeds. Execution of any state-level livestock breeding program is also a major challenge due to lack of technical manpower. Animal husbandry and veterinary officials are overburdened with twin responsibilities of working for animal health as well as breed improvement programs in the state. Another significant problem is that depending on the relative economic importance of the species, large ruminants are most prioritized, and other species receive less attention. Lack of timely revision of breeding policies, poor outreach of schemes, the inadequacy of

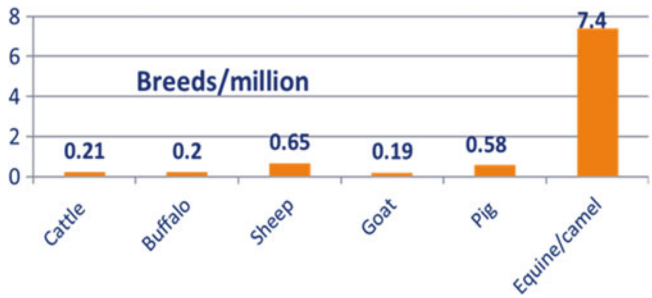

Fig. 10.3 Breeds (per million animals) of different farm species in India

funds, and an insufficient number of breeding males are other issues that need to be dealt with.

10.4.7 Inadequate National Animal Identification/Recording System

Animal Husbandry Department at national and regional levels maintains data about livestock population at the village level. AGRI-IS (AnGR of India-Information system) developed by NBAGR provides information about demographic as well as physical and production traits for different livestock breeds of the country. However, there is a lack of documentation about the physical and genetic characteristics of many unexplored populations of the country. There is no systematic performance recording of elite animals under field conditions and inadequate integration of data from different agencies like central and state breeding farms, ICAR, and military farms. As a result, the execution of selection schemes and quantification of the impact of improvement programs becomes a herculean task.

10.4.8 Lack of Scientific Evidence in Support of Unique Attributes of Farm Animals

Indigenous livestock breeds cannot compete in quantity with industrial livestock systems; it thus makes sense to focus on their unique qualitative aspects as a means of conservation and source of livelihood. Local breeds can produce unique products that can generate significant levels of demand and can help rescue a threatened breed from further decline or extinction. Fortunately, many local breeds and species have a large but often unrecognized potential to produce items that customers appreciate and demand. Many local breeds produce items with particular qualities such as coloured wool, patterned hides, super-fine fiber, meat that is especially tasty, or milk that has special qualities. Products of local breeds are often processed in traditional ways. The need to conserve milk or meat without refrigeration has led to the development of unique sausages and cheeses. Some of the unique traits of indigenous livestock and poultry that need immediate scientific attention are better taste and flavour of Kadaknath chicken meat and its claimed medicinal value, Pashmina from Changthangi goats, camel milk for its medicinal properties, high-fat milk of Bhadawari buffalo, keeping quality of Chilika buffalo curd, and Churpi—a traditional dairy product of Himalayan region. It can further lead to better understanding of the technological requirements for producing products tailored to urban consumer preferences; awareness among communities, policy makers, and private enterprise about the economic opportunities inherent in local breeds; as well as insights into the potential special label/brand for products for conserving livestock systems.

10.4.9 Coordination Between Agencies

Vast networks of national-level agencies like the Department of Animal Husbandry, Dairying and Fisheries (DAHD & F), Indian Council of Agricultural Research, National Dairy Development Board (NDDB), Agricultural Universities, and Veterinary Universities are involved in AnGR management. Even at the state level, there exist state Animal Husbandry Departments, Biodiversity Boards, Livestock Development Boards, and committees that are associated with policy formulations related to farm animals. Some nongovernment agencies are also actively involved in the conservation and utilization of the indigenous stock at the national and local levels. Over the years, there has been an emergence of many private players that aim to produce high-quality semen doses for some of the indigenous dairy bovine breeds. Despite the involvement of so many participants, a lack of coordination in the implementation and monitoring of programs has not yielded promising results in genetic improvement and inventorization of indigenous germplasm.

10.4.10 Climate Change

Livestock systems globally are changing rapidly in response to human population growth, urbanization, and climate change. Of these, global warming has been recognized as the most challenging environmental problem threatening biodiversity worldwide. Climate change has progressed rapidly in recent years, and given the climate sensitivity of the agriculture and livestock sector, this is a matter of great concern. Since 1900, the global temperature has increased by 0.065 °C per decade, but since 1990, it increased by 0.136 °C per decade. The Intergovernmental Panel on Climate Change Fifth Assessment Report states that an increase of 2–3 °C above pre-industrial levels may result in the loss of 20–30% of plant and animal species. As per the Global Risks Report 2019, the failure of climate change mitigation and adaptation has been ranked as one of the most impactful risks for the past 5 years. Climate change will further exacerbate the effects of other stressors and is likely to become the dominant direct driver of biodiversity loss by the end of this century (IPCC 2014). There is no denying the fact that in times to come, climate change is expected to be a major force testing resilience of global food production systems. In order to ascertain adaptation potential in times of uncertainty, maintenance of sufficient diversity of animal genetic resources (AnGR) would be an absolute prerequisite.

10.5 Possible Solutions

1. Augmenting the productivity of indigenous animals should be the focus of different agencies associated with AnGR of the country. Infrastructure for procurement and management of elite bulls and, subsequently, collection of semen from them should be created with utmost priority. Indigenous breeds should be exploited maximally for breed improvement programs.
2. Focus needs to shift from maintaining high-input-output crossbreds to the traditional extensive livestock production systems which rely on the adaptive capabilities and resilience of local breeds.
3. Attempts should be made to periodically review the breeding policy of all states with the focus on devising breed-specific breeding strategies.
4. There is a need to explore and characterize new breeds of indigenous livestock and poultry with unique characters specifically from remote and inaccessible regions of the country. This would help to bridge the gap between descript and non-descript populations and would pave way for documentation of non-documented populations. This can be done by taking up as a mission mode project based upon inputs received from state animal husbandry departments and livestock development boards. Varieties for livestock species evolved by different organizations in India should also be registered.
5. Maintenance of livestock/poultry genetic diversity is the basis for improvement and conservation programs as well as a strategy for mitigation of gradual environmental changes such as climate change and the effects of unforeseeable emergencies in the future.
6. A national-level database with the explicit details of Indian livestock breeds, their breeding tracts, numbers, characteristics, genetic makeup, and conservation units is the need of the hour.
7. Sharing and updating data between DAHD & F, NDDB, ICAR, State Animal Husbandry Departments, State Livestock Development Boards, and veterinary universities should be done on a regular basis for real-time evaluation of impacts of various policies and programs.
8. Conservation of livestock and poultry diversity can be achieved with a multi-pronged approach that involves designating "hot spots" for AnGR biodiversity, declaring existing state/central breeding farms as germplasm repositories for production of breeding males, updating the "National Watch List" of endangered breeds on the basis of census data, prioritizing breed for conservation, and implementing combinations of conservation methods (in situ or ex situ) for each designated breed.
9. National gene bank should be set up that can act as the nodal repository of the indigenous genetic material of the country (DNA, ova, semen, embryo, somatic cells, etc.), and it should be complemented by regional gene banks.
10. Create public awareness about the importance of indigenous breeds and encourage community-based breeding programs. Livestock keepers involved in

the conservation of indigenous germplasm should be encouraged by felicitation in the form of Breed Conservation Awards at the regional and national levels.

11. Government agencies should devise a mechanism to ensure the availability of feed and fodder, health coverage, and financial support to make livestock keeping an economically viable proposition. To enhance the productivity of animals, the government must proactively get involved in creating fodder cooperatives and ensuring the availability of grazing lands to the livestock.
12. Thorough scientific investigations are warranted to establish unique attributes of indigenous livestock products. The novel information generated needs to be propagated to the grassroots level through awareness camps, training programs, or interactions under the "Mera Gaon, Mera Gaurav" initiative of the government. If the provision of organized markets for the unique products of indigenous livestock is ensured, indigenous germplasm would be automatically conserved.

10.6 Conservation Efforts

Conservation is defined as "the management of human use of the biodiversity so that it may yield the greatest sustainable benefit to present generation while maintaining its potential to meet the needs and aspirations of future generations." Conservation of animal genetic resources is an important Strategic Priority Area of the Global Plan of Action. Effective conservation of genetic resources is possible only if the existing biodiversity is identified and documented adequately and there is full participation in conservation efforts of communities keeping the animals.

There are a number of reasons why animal genetic resources should be conserved:

- To meet present socioeconomic demand and ensure livelihoods of poor rural communities.
- As an insurance against unforeseeable future changes.
- For regenerating the population after natural disasters.
- To rescue rare or endangered species or breeds.
- For providing a source of genetic material for research purposes.
- To maintain indigenous livestock gene pool diversity.
- For cultural and historical reasons, since identity of most communities is reflected by the type of breeds they keep.

Conservation actions are commonly grouped into three categories (FAO 2020):

- *In situ conservation*: Support for continued use by livestock keepers in the production system in which the livestock evolved or are now normally found and bred.
- *Ex situ in vivo conservation*: Maintenance of live animal populations not kept under their normal management conditions (e.g., in zoological parks or

governmental farms) and/or outside the area in which they evolved or are now normally found.

- *Ex situ in vitro conservation*: Conservation under cryogenic conditions including the cryo-conservation of embryos, semen, oocytes, somatic cells, or tissues having the potential to reconstitute live animals at a later date.

10.6.1 In Situ Conservation

In situ conservation primarily involves the active breeding of animal populations in such a way that diversity is optimally utilized in the short term and maintained for the longer term. It ensures that breeds are maintained in a dynamic state since they evolve by slow and balanced adaptation to the conditions in which they are maintained. In situ maintenance of the genetic diversity is primarily the responsibility of the breeders for which the following activities are important:

- Promotion of indigenous germplasm via association of breeds with products having geographical indications or traditional importance.
- Development of niche marketing facilities that provide breeders with an economic incentive for raising their respective breed.
- Provision of incentives or subsidies (e.g., from the government) for keeping at-risk breeds.
- Recognition of breeders contributing to conservation in the form of awards or honours.
- Extension programs to improve management of at-risk breeds.
- Awareness generation regarding the unique traits of indigenous animals that may be valuable in particular circumstances.
- Conservation breeding programs that maintain breed-specific traits and limit inbreeding.
- Genetic improvement programs for at-risk breeds that aim to increase their production and/or productivity.
- Community-based conservation programs wherein the local people are the primary stakeholders responsible for the development and conservation of AnGR.

Various breed societies and nongovernment organizations (NGOs) are doing exemplary work for in situ conservation of livestock. Some of these are listed in Table 10.5.

10.6.2 Ex Situ In Vivo Conservation

This is achieved by the maintenance of the small population of a breed at a place away from the main breeding tract. This type of conservation is particularly important for genetically eroded breeds that have very small populations and are sparsely

Table 10.5 Breed societies/NGOs associated with in situ conservation

S. no.	Name of breed society or NGO	Location	Breeds covered
1.	ANTHRA	Hyderabad and Pune	Deccani sheep
2.	SEVA (Sustainable Agriculture and Environment Voluntary Action)	Madurai, Tamil Nadu	Malaimadu cattle Umblachery cattle Pulikulam cattle Vembur sheep Katchaikatty sheep Toda buffalo
3.	SURE (Society for Upliftment of Rural Economy)	Barmer, Rajasthan	Tharparkar cattle
4.	Sahjeevan	Bhuj, Gujarat	Banni buffalo
5.	Tona farms	Kolkata, West Bengal	Garole sheep
6.	Timbaktu Collective	Anantapur, Andhra Pradesh	Hallikar cattle
7.	Jal Kranti Trust	Junagarh, Gujarat	Gir cattle

scattered in their home regions. This may be in the form of an organized herd maintained in a research institution, bull mother farm, state-owned livestock farm, zoo, or breed park. These farms generally maintain economically important breeds of various animal species and are used as demonstration centers as well as for the production and dissemination of superior germplasm. This population can be subsequently used for the regeneration of an endangered breed if the need arises. However, the genetic constitution of a small population at a farm can change rapidly and is prone to a reduction in genetic variability. So, the most important challenge in managing the population in ex situ conservation is to ensure that sufficient genetic diversity is maintained.

10.6.3 Ex Situ In Vitro Conservation

It basically involves cryo-conservation of semen, ova, embryos, or cells for potential future use in breeding or regenerating animals.

1. *Semen*: Technologies exist that have made collection, cryopreservation, and subsequent utilization of semen for artificial insemination possible in different livestock species. The National Bureau of Animal Genetic Resources (NBAGR) also has a National Semen Bank where the semen of indigenous livestock breeds has been cryo-conserved for posterity which includes the following.

Cattle	Amrit Mahal, Dangi, Gangatiri, Gir, Hallikar, Hariana, Kangayam, Kankrej, Kherigarh, Khillar, Krishna Valley, Ongole, Ponwar, Punganur, Rathi, Red Kandhari, Red Sindhi, Sahiwal, Tharparkar
Buffalo	Assamese Swamp, Banni, Bhadawari, Jaffarabadi, Murrah, Nili-Ravi, Pandharpuri, Surti, Tarai, Mehsana, Toda, Nagpuri
Goat	Black Bengal, Chegu, Osmanabadi, Assam Hill
Sheep	Garole
Equines	Marwari, Zanskari
Yak	Arunachali
Camel	Jaisalmeri

However, preservation of semen has the disadvantage that only a single complement of chromosomes is preserved. Therefore, regeneration of a breed from frozen semen in one generation would be possible only if living females of that breed are available, or else several generations of up-gradation would be required to reestablish a breed. Moreover, mitochondrial genes are not preserved in semen. It is an established fact that variation in mitochondrial genes between breeds and within breeds contributes to genetic diversity. This represents another demerit of using semen for cryopreservation.

2. *Epididymal sperms*: Although sperms are produced in the testicles, their maturation and storage until ejaculation occur in the epididymis. Technology to collect and preserve cauda epididymal semen from slaughtered animals has been standardized in a number of livestock species. This technology is particularly promising to obtain semen from an elite animal that dies before contributing semen to semen banks. At NBAGR, successful kidding from a doe inseminated with semen recovered from cauda epididymis of a dead buck has been achieved, and now efforts are underway to cryo-conserve epididymal sperms from rams.
3. *Oocytes*: Considerable progress has been made in cryopreservation of oocytes in the last decade, and viable oocytes have been recovered after freezing and thawing in a great number of animal species, viz., cattle, pigs, sheep, rabbits, mice, monkeys, goats, horses, and buffaloes across the globe. It is possible to restore a lost breed by using cryopreserved oocytes and semen. Live births from cryopreserved oocytes have been reported in cattle and horses.
4. *Embryos*: Embry banking is a good alternative for conserving genetic diversity and restoring an original breeding population since embryos are diploid in nature and include both nuclear and mitochondrial genes. However, high cost and the need for greater technical capacity are its demerits. Live births from frozen-thawed embryos have been reported in bovines, pigs, sheep, goats, and equines, but the greatest success has been achieved in cattle, a species in which cryopreservation of embryos has become a routine procedure.
5. *Somatic cells*: The establishment of somatic cell banking for the purpose of recovering endangered mammalian breeds and species (threatened with extinction) appears to be an important approach since somatic cells are diploid in nature with information of the full genetic code of an animal. Viable cryopreserved cell lines can be obtained from a very small amount of biopsy material. In contrast to

germ cells, embryos, and generative tissues, the cryopreserved somatic cells are capable of regeneration even after repeated thawing and, therefore, may serve as an infinite source of biomaterial for use in assisted reproductive technologies and biological research. Isolation of ear marginal or fetal skin fibroblasts using adherent culture has been established for some species to develop fibroblast cell banks. The development of such cell banks, particularly for endangered species, can provide an excellent resource for biological research and preserve valuable genetic materials. NBAGR has also made good progress in this direction by cryopreserving fibroblast cells from many livestock breeds, namely:

(a) Camel: Double-humped (*Camelus bactrianus*), Kutchi, Kharai, Bikaneri, Jaisalmeri.
(b) Horses: Manipuri, Marwari, Zanskari.
(c) Donkey: Ladakhi, Kutchi, Halari.
(d) Yak: Ladakhi.
(e) Mithun: Nagaland.

6. *DNA*: Although cryopreserved DNA cannot by itself be used for the generation of a live animal, it can be used for the characterization of genes on various chromosomes which will likely be an integral part of conservation. Analysis of the genetic structure of populations can provide information on the levels of genetic admixture within a breed or on the levels of introgression from other populations or breeds. This knowledge can in turn be utilized for setting up conservation priorities.

Conservation strategies (in situ and ex situ) vary in their capacity to attain different objectives; hence the choice between them depends upon the conservation aims. The importance of in situ conservation has been acknowledged by the Convention on Biological Diversity (http://www.cbd.int/convention/articles/?a=cbd-08) with ex situ conservation being a complementary activity. For long-term in situ conservation, maintenance of cryo-conserved germplasm would be an additional asset. In simple terms, in situ and ex situ conservations are complementary to each other rather than mutually exclusive.

10.6.4 Breed Conservation Programs Adopted by Various Agencies

There are many livestock breeds or populations for which in situ conservation programs have been coordinated by DAHD & F, ICAR, and state animal husbandry departments in different states from time to time. The details of these breeds are as follows.

Department of Animal Husbandry, Dairying, and Fisheries

Horse: Spiti, Bhutia, Manipuri, Kathiawadi, Gray Sindhi, and Marwari.
Pigs: Doom, Zovawk, Ankamali, Don, Mali, and Ghungroo.
Yak: Local and Hazi yak.
Goats: Chegu, Black Bengal, Malabari, Attappady, and Berari.
Sheep: Bandur, Bonpala, Nilgiri, Muzaffarnagari, and Ramnad White.
Camel: Kachchi.
Chicken: Harringhata Black and Naked Neck.

Indian Council of Agricultural Research

Cattle: Tharparkar, Krishna Valley, Bargur, and Ongole.
Buffalo: Toda.
Sheep: Nilgiri, Magra, Kilakarsal, and Poonchi.
Goat: Beetal and Surti.
Horse: Spiti.
Chicken: Harringhata Black.

10.7 Recommendations

1. Urgent need of undertaking rigorous survey programs to characterize non-descript populations of livestock species.
2. National-level database with the explicit details of Indian livestock breeds.
3. Breed-wise national breeding policy.
4. Conservation of breeds at-risk.
5. Public awareness about the importance of indigenous breeds.

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Part IV
Ecosystem Diversity

Chapter 11
Agricultural Crop Diversity: Status, Challenges, and Solutions

Anurudh K. Singh

11.1 Introduction

India is rich in biological diversity, being one of the 17 mega-biodiverse countries in the world. It has an amazing range of habitats available in its 10 + 1 bio-geographic zones (Singh 2017a, b), habiting about 20,141 taxa of higher plants (angiosperms) with 17,926 species belonging to 2991 genera and 251 families, representing approximately 7% of the described higher plant species in the world (Karthikeyan 2009). As per archaeological evidence, the Indian Subcontinent has played an important role in the origin and evolution of agriculture from the hunters-gatherers stage to domiculture and to settled agriculture exploiting both flora and fauna. These efforts led to the evolution of the Indus Valley Civilization developed and flourished nearly 5000 years ago (3300–1300 BCE; mature period 2600–1900 BCE), Vedic Civilization (1500–500 BCE), Mahajanapada (600–400 BCE), etc., as gleaned from the findings of numerous archaeological sites across the country. Recent studies have shown that the process of origin and evolution of agriculture predominantly occurred at 21 agricultural biodiversity heritage sites, spread over the subcontinent with domestication, adaption, and cultivation of many crop species suited to diverse ecologies offered by the subcontinent (Singh 2015). These fell parallel to 21 agro-ecological zones, identified for the subcontinent (Sehgal et al. 1992) with a rich diversity of crops and genetic diversity in adapted crop species (Fig. 11.1), throughout ecological zones and beyond, under more than 120 production systems.

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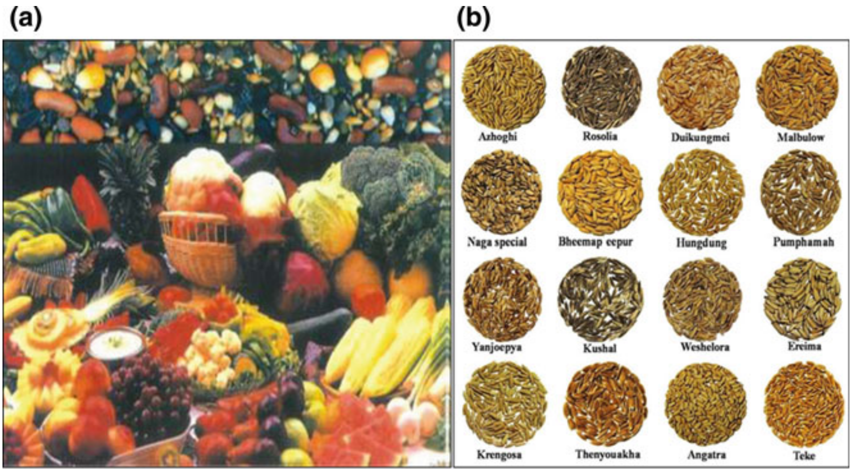

Fig. 11.1 (**a**) Rich crop diversity in India (source: NBPGR guidelines for germplasm registration); (**b**) rice crop diversity in northeast states of India. (Source: Umakanth et al. (2017))

11.1.1 Crop Diversity in India

Considering the above facts, the famous Russian botanist and plant explorer N.I. Vavilov in the 1920s recognized the Indian region among the eight centers of crop origin and diversity of cultivated plants. This was upheld by the previous and subsequent scientific studies, starting from the time of Alphonse de Candolle (1883) identifying around 45 crop species. Vavilov (1935) listed 172 plant species, including 117 for the Indian mainland and 55 from the Indo-Malayan region; Harlan (1975) associated 24 plant species from India and 73 from Southeast Asia; and Zeven and De Wet (1982) listed 166 plant species, out of a total of 2489 species distributed in 12 regions of global agrobiodiversity (Arora et al. 2006). A recent, literature research-based survey indicates that around 215 economically important plant species were domesticated by Indian communities in different parts of the subcontinent. Some important ones are listed in Table 11.1.

Being the seat of ancient agriculture and civilizations, agrobiodiversity of the subcontinent was further enriched and revolutionized with the introduction of many plant species domesticated elsewhere in the old and new world (Singh 2016; 2017a). It is reflected by the presence of American cereals such as maize, and grain amaranth; vegetables such as pumpkin, etc.; African cereals such as pearl millet, sorghum, etc.; and West Asian legumes such as chickpea, field pea, grass pea, fenugreek, etc. in the archaeological remains (Saraswat 1992). The introduction of exotic crops got a further boost during the medieval period, after the discovery of the sea route to India in 1498 by Vasco da Gama's. The Portuguese, British, Dutch, French, and Spanish intensified the trans-oceanic and maritime trade with India, bringing more crop species to the Indian shores (sixteenth century), diversifying and enriching the agricultural crop diversity and gene pools of the subcontinent. The Moguls,

Table 11.1 Crop species domesticated/first brought in cultivation in India (source: Singh 2017a)

Crop group	Crops
Cereals and millets	Rice, barnyard millet, finger millet, little millet, kodo millet, yellow foxtail millet, Job's tears
Grain legumes	Pigeon pea, moth bean, black gram, green gram, rice bean
Oilseeds	Indian mustard, rapeseed, sesame, Karanj oilseed
Forage crops	Indian sandbur, *Digitaria*, prickly *Sesbania*, wild bean
Fiber crops	Indian hemp, white jute, sun hemp, diploid tree cotton
Vegetable	Jimikand, ash gourd, sword bean, Indian lettuce, ridge gourd, sponge gourd, balsam apple, bitter gourd, small bitter gourd, round gourd, oil radish/mungra, eggplant, snake gourd, pointed gourd
Fruits and nuts	Bael, jackfruit, star fruit, almondette/chironji, ker, karonda, sour lime, citron, temple orange, sour orange, lemon, tight-skin orange, *Cordia*, Himalaya hazelnut, Indian gooseberry, Indian plum, kokum, *Grewia* or phalsa, wood apple, mango, khirni, Spanish cherry, banana, Mysore raspberry, yellow Himalayan raspberry, jamun/jawa plum, rose apple, Indian jujube/ber
Species and condiments	Bengal cardamom, Indian dill, tejpat, Indian cassia, dalchini, cinnamon, turmeric, mango ginger, zedoary, cardamom, Malabar tamarind, chandramula, curry leaf, long pepper, black pepper, ginger
Medicinal and aromatic plants	Musk mallow, kalmegh, Indian belladonna, Indian barberry, marijuana, Safed musli, gandira, guggal, babchi, black turmeric, lemongrass, palmarosa, citronella grass, *Datura*, spikenard, holy basil, Indian gentian, serpentina, pilu, nux vomica, chiretta, arjun, bahera, harara, giloe, khas, Indian ginseng
Ornamental crops	Golden shower, *Crossandra*, *Hiptage*, jasmine, Champa, magnolia, oleander, Indian coleus, false ashoka, rose
Plantation/commercial crops	Arecanut, sugar palm, toddy palm, coconut, date palm, betel leaf, rubber, sugarcane, banana
Agroforestry crops	Gum Arabic/babul, catechu/khair, neem, Indian mahogany, Indian rose wood, mahua, khejri, Indian amulet tree, dhaincha
Others	Bamboo, cotton fiber, Indian arrowroot, *Dendrocalamus*, tendu, Nilgiri nettle, indigo, Himalayan mulberry, madder, soapnut, Sal timber

Spaniards, Portuguese, and British introduced a number of cultivated plant species such as apple, pear, apricot, grape, almond, date palm, maize, potato, tomato, beans, onion, garlic, chilli, lentil, rubber, pineapple, cashew nut, tobacco, etc.; Arabs brought clove, coriander, cumin, fennel, coffee, cocoa, cinchona, strawberry, blueberry, etc.; and the Chinese brought peach, litchi, tea, soybean, etc. This process continues even today with some recent introductions of several fruit species, such as kiwi fruit, macadamia nut, etc., and ornamental plant species such as cape jasmine, *Gazania*, etc., from the New World, further enriching the crop diversity. The prevalence of the plant introductions from times immemorial has gone to the extent that many have naturalized to diverse agroclimatic conditions offered by the subcontinent, generating new variability and further revolutionizing crop diversity.

Consequently, making India the primary center of diversity for crops of Indian origin that include not only food crop species but also many other of economic value, such as fiber, fodder, and medicinal plant crops like *Rauvolfia serpentina*, *Saussurea costus*, etc.

It is also the secondary center of genetic diversity for tropical American crops, such as maize, amaranths, tomato, chillies, pumpkin/Cucurbita species, and chayote/chou-chou, and African crops such as finger millet, pearl millet, sorghum, cowpea, cluster bean (trans-domesticate), okra, sesame, niger, safflower, etc.

Finally, India is the regional center of diversity for crops like maize, barley, amaranth, buckwheat, proso millet, foxtail millet, green gram (mung bean), chickpea, bottle gourd, snake gourd, and some members of the family Brassicaceae, etc.

Further, geographical contiguity with the Far East and the South/Southeast Asian region also added to regional diversity in rice bean, sword bean, citrus, small cardamom, *Saccharum*, ginger, turmeric, and tuber crops, particularly aroids like taros and yams, bamboos, etc.

All India Coordinated Research Project on Ethnobiology has collected traditional knowledge about the use of 10,000 plants, of which 2500 plants are used in the traditional medicine systems, Ayurveda, Siddha, Unani, Sowa-Rigpa or Amchi, etc., and another 950 used by various tribes, worthy of scientific scrutiny (Pushpangadan et al. 2018). Around 3900 wild plant species are used as subsidiary edible food/vegetable, of which at least 250 of them are worthy of investigation. Around 400 plant species are used as fodder, of which 100 are worth recommending for wider use; 300 (wild species) are used by various tribal groups as botanicals (fungicides or pesticides); 175 are quite promising for development as safe pesticides; 300 are used as a source of gum, resin, and dye; and 100 are used as sources of incense and perfumes (Pushpangadan et al. 2018). Each of these plant species has the capacity to come under regular cultivation for their commercial exploitation under agriculture, increasing their productivity, facilitating conservation, and restricting erosion due to direct exploitation from nature, thereby contributing to increased crop diversity.

11.1.2 Wild Relatives of Crops

The wild relatives of crop species, particularly those of Indian origin, constitute another rich reservoir of genetic diversity in the Indian gene center. This diversity is of immense value to plant breeders looking for the genes beyond the primary gene pool of cultivated species and often offers good sources of diversity particularly biotic and biotic stresses, because of their inherent resilience, continuously evolving due to the continued fight for survival against nature's vagaries. The contribution of wild relatives toward crop improvement has been well exemplified in many crops such as rice, wheat, sugarcane, potato, and tomato, besides several forages and other crops (Rick 1979; Brar 2005; Hajjar and Hodgkin 2007; Reem and Toby 2007; Kole 2011; Singh 2017a, b). A recent study has estimated the presence of more than 900 wild relatives of crops and related taxa occurring in India belonging to various

Table 11.2 Number of cultivated species and their wild relatives found in India representing agricultural crop diversity under different crop groups (source: Singh et al. 2013)

S. no.	Crop groups	Number of cultivated plants	Number of wild relatives
1	Cereals	15	37
2	Millets	13	33
3	Grain legumes	18	36
4	Vegetables	105	168
5	Fruits and nuts	117	176
6	Oilseeds	19	13
7	Sugar-yielding plants	3	18
8	Fiber crops	12	23
9	Forage/fodder crops	96	33
10	Spices and condiments	46	123
11	Plantation crops	20	21
12	Medicinal and aromatic plants	89	58
13	Ornamental plants	182	90
14	Agro-forestry species	35	31
15	Other crops	41	42
	Total	**811**	**902**

crops, spread over different biogeographical regions of the Indian Subcontinent (Singh et al. 2013, 2017a, b).

The number of cultivated species (indigenous and exotic) and wild relatives of crop species belonging to various crop groups found in India, representing a present spectrum of crop diversity, is presented in Table 11.2.

11.2 Need for Conservation of Crop Diversity (Due to Value and Threat)

The crop diversity provides basic building blocks, i.e., the genes conferring desirable traits for genetic improvement of crops by breeding them into the crop species to produce cultigens with greater resilience against the vagaries of nature (contributing to the reduction of economic yield) and components to increase productivity, to improve present yield, and to sustain it in all the times to come. Therefore, it needs to be captured and conserved for sustainable use. It becomes even more crucial in the present scenario of climate change, to engineer cultigens that can stand against rising adverse environments and meet the challenges of the ever-growing population and market needs.

Further, the crop diversity is being eroded at a very fast pace, for example, 5000 folk rice has been lost from north-east India only (Fig. 11.1), since the Green Revolution (Jackson 1994), whereas as per the estimate of the Ministry of Environment and Forest, around 30,000 rice varieties were grown at the time of independence in India, which are feared to reduce to 50 by 2000 (envfor.nic.in:2000). Additionally, many wild relatives of crop species are under threat because of diverse reasons including infrastructure developments and climate change. The International Union on Conservation of Nature in Red List of Threatened Plants in 1997 listed around 1255 species from India (Rao et al. 2003). Of these, around 306 fall in the category of wild relatives of crop/cultivated plant species. This scenario demands that the available genetic diversity of crops and their wild relatives should be captured and conserved on priority before it is lost forever. Loss of genetic diversity would mean loss of opportunities for genetic improvement of crops by present and future generations in their effort to provide food and nutritional security.

11.3 Status of Captured/Assembled, Conserved, Characterized, and Utilized Crop Diversity

Historically, the collection and conservation of crop diversity species for use in crop improvement in India were initiated with the establishment of the Imperial Agricultural Research Institute in 1905 at Pusa, Darbhanga District, Bengal (now in Bihar). This institute was shifted to New Delhi in 1936 and later in 1947, renamed as Indian Agricultural Research Institute (IARI). The early activities involved frequent multiplication and storage of seeds of diverse collections of crops. To strengthen these efforts, a unit was set up in Botany Division for the assembly of global germplasm in 1941. It was upgraded as the Division of Plant Introduction in 1961 and further upgraded to the National Bureau of Plant Genetic Resources (NBPGR) between 1976 and 1977 with the mandate to manage all activities from collection to management to facilitate use in crop improvement. The establishment of the crop(s)-based research institutes, State Agricultural Universities (SAUs), and All India Coordinated Crop Improvement Projects (AICIP) further provided the impetus to these activities. Consequently, India made significant progress in the collection of crop diversity to enable capturing the total spectrum of genetic diversity, searching for desirable genes, promoting conservation and use of crop diversity, and facilitating genetic improvement of crops for food and agriculture.

11.3.1 Collecting Crop Diversity

11.3.1.1 Status

By 2017, a total of 2,71,600 germplasm accessions (85.63% cultivated, 14.37% wild) have been collected through around 2695 exploration trips in collaborative mode involving crop-based ICAR institutes, SAUs, Krishi Vigyan Kendras, and other national and international organizations, representing over 2000 crops/species. Crop group-wise (14 groups) accessions collected are depicted in Fig. 11.2. These

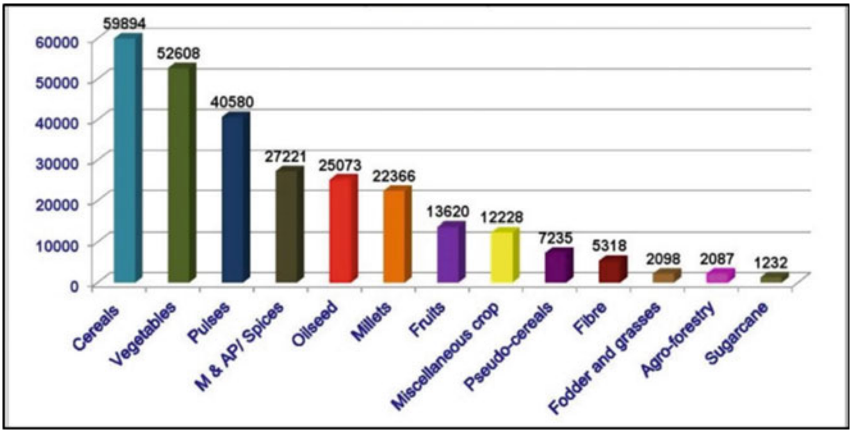

Fig. 11.2 Crop group-wise collections made by NBPGR and collaborators between 1946 and 2017. (Source: Ahlawat et al. 2019)

include 17 special rescue missions, executed in diversity-rich areas where diversity was under imminent threat or hit by natural or man-made disasters and could have been lost forever. In these missions, nearly 8000 accessions of landraces and species of potential value were gathered. The collections include rare and unique collections from different regions of the Indian subcontinent, for example, deep water-tolerant, cold-tolerant, aromatic, good-taste, salt-tolerant, drought-tolerant, and early-maturing (sathee rice: 60 days) landraces in the case of rice. Around 250 species (~10,000 accessions) have also been collected including around 98 ancestral wild relatives of different agri-horticultural crops (Ahlawat et al. 2019).

These collections have been mapped in nine crops, viz., rice, wheat, maize, *Brassica* spp., pigeon pea, sesame, sorghum, pearl millet, and tomato, using modern tools of GIS and GPS. Gaps in germplasm collections have been identified, to plan and undertake future explorations.

Further, to provide technical inputs facilitating identification, authentication, and taxonomic identity of the collected taxa, a National Herbarium of Cultivated Plants (NHCP) has been established in Plant Exploration and Germplasm Collection Division at NBPGR. A total of 22,566 herbarium specimens and more than 6000 digitized images are available in the NHCP for study and referral use by students and researchers.

11.3.1.2 Challenges and Solutions

Despite concerted efforts to capture genetic diversity, there remain geographical and genetic diversity gaps in collections, particularly in the case of marginal crops and their wild relatives, for different reasons. In contrast, in the case of major crops, large collections have assembled with many duplicates, because of the non-application of appropriate collecting and/or sampling strategies to ensure the collection of genetically distinct genotypes. The lack of capturing of the total spectrum of available genetic diversity in collections has also been a contributor, because most collections were made from farmer's fields along the highways and roads, overlooking the interior or non-accessible difficult landscapes (hills, valleys, etc.) habituated by the tribal communities and traditional farmers, still practising the traditional agriculture with a significant diversity of heterogenous landraces, farmer's/local varieties, and extant varieties having a major reservoir of genetic diversity. Further, most expeditions have been for collections of many diverse crops; without experts for every crop may have led to biased collections without the application of appropriate scientific rationale.

Consequent to the presence of wild relatives in difficult forests and marginal agricultural areas, these collection missions did not have the desired emphasis on the collection of genetic diversity in wild relatives and/or ancestral species. Most wild relative collections are represented by a few collections of specific wild species rather than the range of genetic diversity within a species found in different areas of their geographical distribution. This needs to change with greater emphasis on the collection of the available range of genetic diversity among species.

To cover the geographical range of distribution and cultivation of the wild relatives and cultivated species respectively, the geographical/GIS mapping of collections must be performed without exception to enable performing gap analysis for future collections. Efforts should be made to establish access to difficult unexplored areas and ecologies to provide coverage to the whole geographical distribution. Similarly, major constraints should be identified in most crops followed by a search for genetic variability for these constraints in the available collections to identify genetic gaps for desired and rare genes/alleles. Considering the above efforts, only pointed collections must be made to fill the geographical and genetic diversity gaps, searching for specific genetic diversity in various taxonomic entities. Greater emphasis on the collection of wild relatives' genetic diversity from diverse areas of geographical distribution should be a priority.

For collections, appropriate criteria as per the breeding behaviour of the target species should be identified, to facilitate a sampling design in the target area (landscape) ensuring the collection of genetically diverse entities, and avoiding duplicates. Extension of efforts, e.g., making herbarium of diverse species and genetically diverse forms within species and their digitization, may be another area to help taxonomic research and education. Collection and documentation of indigenous traditional knowledge associated with various collections and biosystematics studies ensuring the taxonomic status and phylogenetic relationships between cultivated species and their wild relatives may be other areas to promote effective management and use of crop genetic diversity.

11.3.2 *Conservation of Crop Diversity*

11.3.2.1 Status

For conservation of crop diversity, a complementary approach, involving both in situ and ex situ conservation technologies, has been adapted to ensure natural dynamism, safety, and economical and effective conservation to provide sustainable support to crop improvement programs to present and future generations. Considering the size of the country and diversity of crops, a network approach has been adopted, facilitating short-, medium-, and long-term conservation requirements with the application of both conventional and biotechnological methods, fulfilling the requirement of complementary conservation strategies facilitating the conservation of total spectrum of crop diversity and of their wild relatives with shared responsibilities, to ensure facilitated access to conserved crop diversity in crop improvement programs.

The national network consists of the National Gene Bank (NGB) at NBPGR, 11 NBPGR Regional Stations situated in different agro-climatic zones, and crop-based National Active Germplasm Sites (NAGS), located generally at various ICAR institutes and SAUs. The network is linked with AICIP, various research institutes (crop- or multi-crop-based institutes, project directorates, and national research centers) in the ICAR, SAUs, etc.

National Gene Bank: It is primarily responsible for the conservation of base collections. It has three constituents:

Seed genebank: The seed genebank is responsible for the conservation of seed accessions on a long-term basis at low temperature (at −18 °C), as base collections for posterity. The present base collection holdings in the NGB are 443,417 belonging to around 2000 species, the fourth largest genetic wealth in the world (Table 11.3).

In vitro genebank: To undertake the conservation of vegetatively propagated crop species, a National Facility for Tissue Culture Repository has been established at NBPGR. This repository maintains 36,300 cultures of 1879 accessions belonging to more than 142 vegetative propagated crop species for short-term and medium-term storage (Table 11.4) under aseptic conditions. In addition, there are several other institutes with repositories of their mandate crop species.

Cryogenebank: Cryopreservation is the storage of biological samples in viable conditions at an ultra-low temperature of liquid nitrogen (−196 to –150 °C). Around 13,363 accessions belonging to 820 species representing all major crops (Table 11.5) have been cryopreserved at moisture contents of 5–8% in the vapour phase of liquid nitrogen.

NBPGR Regional Stations: The NBPGR is responsible for the collection, characterization, evaluation, and/or conservation of germplasm in the region. They also coordinate various PGR activities with other partners of the region. Seven of the regional stations have medium-term seed storage modules (maintained at 4-10 °C) for the conservation of active collections to meet the requirement of the region for

Table 11.3 Status of a number of accessions conserved in the National Seed Genebank (Dec. 2019) (source: Dr. J Radhamani, NBPGR, personal communication)

Crop group	Total acc.
Cereals: Paddy (109327); wheat (33833); maize (11278); others (10340)	164,778
Millets: Sorghum (26109); pearl millet (8423); minor millet (24999)	59,351
Pseudo-cereals: Amaranth (6285); buckwheat (1070); others (393*)*	7748
Grain legumes: Chickpea (14725); pigeon pea (11618); mung bean (4238); pea (4531); cowpea (3864); French bean (3996); cluster bean (4316); horse gram (3067); rice bean (2176); others (14245)	66,776
Oilseeds: Groundnut (13841); *Brassica* (11431); safflower (7432); sesame (10309); soybean (4994); sunflower (1526); others (1062)	60,160
Fiber crops: Cotton (10050); jute (3330); mesta (2022); others (340)	15,742
Vegetables: Tomato (2826); brinjal (4496); chili (5012); okra (3871); onion (1133); others (9535)	26,673
Fruits and nuts: *Buchanania* (97); others (182); custard apple (57); papaya (23)	279
Medicinal and aromatic plants and narcotics: Opium poppy (466); *Ocimum* (620); tobacco (2272); others (4749)	8107
Spices and condiments: Coriander (368); fenugreek (1325; sowa and others (784)	3237
Agro-forestry: Sesbania (648); pongam and others (1002)	1650
Forage: Oats (1387); clover (606); tef (298); marvel grass (335); others (4620)	7246
Grand total	**443,417****

Stored at −18 °C, * including safety duplicates (10,235); representing 2000 species

various crops. The regional stations hold around 98,498 active collections. In addition, plant quarantine is looked after at NBPGR headquarters, New Delhi, and NBPGR regional station, Hyderabad.

National Active Germplasm Sites (NAGS): They are entrusted with the responsibility of crop-specific collection, multiplication, evaluation, maintenance, and conservation of active collections and their distribution to users at the national level. NAGS has a multidisciplinary team of scientists to study all the aspects of crop improvement, production, and management. Therefore, NAGS, in addition to conservation, are well equipped for the evaluation of germplasm and generate information on the potential value of accessions. Eleven of these have been provided with medium-term seed storage modules, to facilitate the use of active collections in research and breeding programs. The total holdings of more than 40 crop-based NAGS are around 197,979 accessions.

Others: Other organizations linked to this network are International Agricultural Research Centres (IARCs), Genebank for Medicinal and Aromatic Plants established at Central Institute of Medicinal and Aromatic Plants at Lucknow, Tropical Botanical Garden and Research Institute at Trivandrum, and NGOs or professional societies.

Considering the difficulties in the management of large collections in major crops, for improved management and facilitate the use, the concept of core collections, i.e., a minimal set of accessions (1–10%) representing total genetic diversity

Table 11.4 Status of in vitro conserved germplasm in National in vitro Genebank (July 31, 2019). (Source: Dr. Sandhya Gupta, NBPGR, personal communication)

Crop group	Genera	Species	Culture	Accessions	Major collection
Tropical fruits (banana)	1	15	9000	431	*Musa* spp. (431)
Temperate and minor tropical fruits (apple, apricot, blackberry, blueberry, pear, strawberry)	10	42	8500	358	*Actinidia* spp. (6), *Aegle marmelos* (2), *Artocarpous lakoocha* (1), *Fragaria* x *ananassa* (81), *Malus domestica* (30), *Morus* spp. (61), *Prunus* spp. (15), *Pyrus communis* (68), *Rubus* spp. (62), *Vaccinium* spp. (21)
Tuber crops (sweet potato, taro, yam)	5	14	6500	518	*Alocasia indica* (4), *Colocasia esculenta* (90), *Dioscorea* spp. (154), *Ipomoea batatas* (260), *Xanthosoma sagittifolium* (10)
Bulbous and other crops (garlic, gladiolus)	4	13	4000	171	*Allium* spp. (157), *Dahlia* sp. (6), *Gladiolus* sp. (7)
Medicinal and aromatic plants	25	34	4000	174	*Coleus forskohlii* (14), *Plumbago zeylanica* (19), *Rauvolfia serpentina* (13), *Tylophora indica* (10), *Valeriana wallichii* (16), etc.
Spices and industrial crops (ginger, turmeric, pepper, cardamom, vanilla, hops, jojoba)	8	24	4300	227	*Curcuma* spp. (110), *Elettaria cardamomum* (5), *Humulus lupulus* (8), *Piper* spp. (7), *Simmondsia chinensis* (12), *Vanilla planifolia* (4), *Zingiber* spp. (80)
Total	**54**	**142**	**36,300**	**1879**	

has been used. The core collection has been established in several field crops such as rice, pearl millet, sorghum, pigeon pea, chickpea, groundnut, etc. [IRRI and ICRISAT (Upadhyaya 2015)], encompassing the Indian crop diversity, which is a major center of diversity of these crops. Cores have also been established in a few crops, such as okra (*Abelmoschus esculentus* L.) (Mahajan et al. 1996) and mung bean [*Vigna radiata* (L.) Wilczek] (Bisht et al. 1998).

Following a comprehensive conservation approach in situ conservation of crop diversity has been attempted with the establishment of sanctuaries in the Tura range of Garo Hills, Meghalaya, for conservation of Citrus and Musa species, and for Rhododendrons and Orchids in Sikkim. Organizations such as the Foundation for

Table 11.5 Status of germplasm in National Cryo-Genebank (December 31, 2019) (source: Dr. Rekha Choudhary, NBPGR, personal communication)

Categories	Accessions*	Total
Recalcitrant and intermediate seeds		**6754**
Fruits and nuts	3519	
Spices and condiments	152	
Plantation crops	39	
Agro-forestry and forestry	1645	
Industrial crops	1365	
Medicinal and aromatic plants	34	
Orthodox seeds		**3902**
Cereals	289	
Millets and forages	293	
Pseudo-cereals	76	
Grain legumes	813	
Oilseeds	668	
Fibers	68	
Vegetables	581	
Medicinal and aromatic plants	1001	
Narcotics and dyes	35	
Miscellaneous	78	
Dormant buds		**387**
Pollen grains		**556**
Genomic resources		**1764**
Total		**13,363**

*No. of species, 820; rare and endangered plants, 99; *varieties, 776; elite, 4; *registered germplasm, 23, *core collection, 323

Revitalization of Local Health Traditions (FRLHT), Bengaluru, and Tropical Botanical Garden and Research Institute (TBGRI) Palode, Kerala, are engaged in in situ conservation of medicinal plants diversity, in addition to sacred grooves in various states that are part of the social system and Indian ethos. For conservation of crop cultigens and landraces with distinct traits, an on-farm conservation approach has been adopted, insulating them from changing social and technological advancement, in the form of Crop Reserves, Mass Reserves or Preservation of Peasant Cultivation dynamic systems. On-farm in situ conservation of rice in Bastar, Madhya Pradesh, by NBPGR, Indra Gandhi Agricultural University, Raipur, and International Rice Research Institute (IRRI) and of pearl millet by International Crops Research Institute for Semi-Arid Tropics (ICRISAT) in Rajasthan have been attempted. In addition, many NGOs such as Beej Bachao Andolan have involved in saving/ conserving seeds of traditional varieties.

11.3.2.2 Challenges and Solutions

In many crops, the accessions assembled through collection and exchange have become too large to manage, evaluate, and use effectively in crop improvement. They have a lot of duplicates, causing difficulties in identifying uniqueness and evaluation of their potential value to facilitate use. Therefore, a probable set of duplicates (with geographical or parental/ancestral similarity) must be removed using conventional and molecular techniques (DNA profiling).

Development of core collections (CCs) representing the total spectrum of variability must be extended to most crops, with priority on major crops. The present cores have been created with a focus on encompassing a total spectrum of phenotypic diversity than encompassing all useful genetic diversity for crop improvement and have not created desired impact on crop improvement. Therefore, the strategy for the selection of representative accessions from different clusters needs improvement to overcome the lacunas (Singh and Nigam 2017).

This can be achieved with rational stratification (sub-grouping) of total collections based on geographical association and taxonomy and inclusion of collection group(s)/gene(s) pool with desirable traits of breeding value, in the random selection of accessions for core, in addition to the selection of accessions from groups (cluster), created on the basis of genetic diversity of morphological traits. It will create more representative core sets, with equal emphasis on the inclusion of ecological, taxonomic, and genic and allelic variability for traits of significance for the genetic improvement of crops. This can be further strengthened with the integration of genomics with molecular characterization and in accession selection strategy, using molecular markers (sequences) and variability within, associated with desirable features. Often molecular level variations are not comparable to phenotypic variations. Therefore, a molecular marker used should be "truly" genomic in the sense of covering both coding and non-coding sequences. In this respect, single nucleotide polymorphisms (SNPs) are the best. Currently, protocols for deciphering genetic diversity at the sub-population level using model-based approaches (Pritchard et al. 2000) and large datasets such as whole-genome SNP variations can be made available to aid the effective development of CCs. This may help to incorporate stable traits in specific breeding, providing greater resilience to the crop species across ecologies with improved quality and productivity. Such core shall promote precise improvement to meet different objectives in different eco-regions, engineering cultigens to face various challenges, including climate change, and nutritional and productivity demands. This will also resolve the concerns regarding non-concentrating on useful genetic diversity in reducing sample size. Further, as the reliability of information is key, accessions with doubtful information must be avoided. The core set must be kept dynamic with the regular addition of variability of traits of breeding value, genes, and alleles conferring rare traits. Diverse cores are more likely to contain adequate sources of many characters; therefore, their amalgamation may improve use value. While some core is still large for easy use, as 10% contains thousands of accessions, there is a need to further reduce size using the appropriate strategy.

Nevertheless, the available cores can still be used in improved management with their use in the identification of gaps (geographical and genetic variability) for priority. They may indicate sources of acceptable expression or suggest a hot spot of diversity to be evaluated or searched in a core subset and of wild related species (Brown 1995). However, documentation of generated information into databases and their linkage with national and international information systems are other areas deserving emphasis to facilitate access and use of crop diversity.

11.3.3 Characterization, Evaluation, and Identification of Sources of Useful Crop Genetic Diversity

11.3.3.1 Status

The process of characterization and evaluation of crop diversity is key to generating information about its potential value and facilitating its use in crop improvement. In India, it started with the beginning of the twentieth century, with emphasis on the major field crops like rice, wheat, maize, sorghum, and pearl millet among cereals; chickpea and pigeon pea among grain legumes; and rapeseed mustard, groundnut, etc. among oilseeds. Later, it was extended to all the other agricultural and horticultural crops. It got intensified with the establishment of crop-specific research centers, directorates, and All India Coordinated Research Improvement Projects (AICRIP) and further intensified globally with the establishment of International Agricultural Research Centres (IARCs) that worked as the international repositories of crop diversity as per the provisions of International Understanding (IU) and Food and Agricultural Organization (FAO) 1983, considering crop diversity (genetic resources) part of human heritage under the auspices of Consultative Group on International Agriculture Research (CGIAR). These efforts resulted in the identification of accessions with required genetic diversity almost for all desirable traits, particularly the one conferring resistance against most biotic stresses that were the main crop yield-reducing factors. Table 11.6 presents the list of traits for which desirable genetic diversity was identified after the systematic scientific screening of many collections in major crops under different crop groups. It reflects the availability of desirable genetic diversity for most traits in the primary gene pool of crop species. However, to meet the challenges of climate change and market forces, the search for new genes conferring desirable crop diversity must continue to engineer new cultigens with greater resilience to upcoming possible yield-reducing factors and to increase yield to provide food and nutritional security to the ever-growing population.

Table 11.6 Characterization and evaluation lead to the identification of accessions with desirable traits in representative crops/crop groups. (Source: Mishra et al. 2006)

Evaluated for desirable traits	Accession eval.
Rice: Blast, sheath blight, bacterial leaf blight, rice tungro virus, grassy stunt virus, yellow stem borer, gall midge, brown planthopper, green leafhopper, drought, salinity	75,000 (DRR)
Wheat: Black, brown and yellow rust, Karnal bunt, leaf blight, loose smut, powdery mildew, drought, salinity, heat	75,200 (NBPGR)
Maize: *Maydis* leaf blight, *Turcicum* leaf blight, banded leaf and sheath blight, sorghum downy mildew, brown stripe downy mildew, post-flowering stalk rot, maize stalk borer	457 (NBPGR)
Chickpea: Wilt, *Ascochyta* blight, multiple diseases, viral diseases, pod borer, salinity	15,000 (ICRISAT)
Pigeon pea: Sterility mosaic, *Fusarium* wilt, *Phytophthora* stem blight, multiple diseases, pod borer, cold	11,034 (ICRISAT)
Mung bean: Yellow mosaic virus, powdery mildew, bacterial leaf spot, multiple diseases, thrips	1834
Urdbean: Yellow mosaic virus, powdery mildew, *Macrophomina* blight, *Cercospora* leaf spot, multiple diseases	
Lentil: Wilt, rust, blight, multiple diseases, drought	5424 9 (ICARDA)
Groundnut: Bacterial wilt, early leaf spot, late leaf spot, rust, pod rot, *Aspergillus flavus*, drought	10,000 (ICRISAT)
Sunflower: Early maturity types, dwarf (head diameter), 100-seed weight, high oil content, downy mildew	6912 (AIROCPO)
Safflower: *Alternaria* leaf spot, aphid	1148 (NBPGR)
Castor: *Fusarium* wilt, whitefly and jassids, extra early maturity, high 100-seed weight (73–86 g), high oil content (54–55%)	2750; 2000 (AIROCPO)
Cotton: ***G. arboretum*** – Early maturity, high oil content (>20%), long staple, high yield ***G. barbadense*****:** Early maturity, high yield, extra-long staple, high seed oil content (> 25%) ***G. herbaceum*****:** Early maturity ***G. hirsutum*****:** Early maturity, high boll weight, high ginning	6000 (CICR)
Jute: Root and stem rot, *Apion*, semi-looper and yellow mite, root-knot nematode, and fiber-quality parameters	2507
Brinjal: Tolerance/resistance to various diseases and stresses, bacterial wilt, root knot nematode and *Phomopsis* fruit rot, shoot and fruit borer	566 (NBPGR)
Tomato: *Fusarium* wilt, fruit rot and early blight, root-knot nematode, tomato leaf curl virus, and bacterial wilt drought and cold tolerance	2000 (NBPGR)
Cucumis sativus**:** Early and determinate type, anthracnose, cucumber scab, bacterial wilt, cucumber green mottle mosaic	
Cucumis melo**:** High yield, downy mildew, *Fusarium* wilt, powdery mildew, watermelon mosaic virus	56
Citrullus lanatus**:** High yield, anthracnose, *Fusarium* wilt, powdery mildew	
Lagenaria siceraria**:** Early maturity, rainy type, summer type, red pumpkin beetle, downy mildew	182
Luffa cylindrica**:** Early maturity, high yield, long, heavy fruits	

(continued)

Table 11.6 (continued)

Evaluated for desirable traits	Accession eval.
***Cucurbita* ssp.:** Bacterial wilt, cucumber mosaic virus, drought, powdery mildew	
Cauliflower: Self-incompatibility, high yield, early maturity, medium to high temperature (30–35 °C), black rot, downy mildew	
Okra: Early flowering, long (height), high yield, powdery mildew, leaf curl virus, fruit borer, etc.	2341 (NBPGR)

11.3.3.2 Challenges and Solutions

Characterization, evaluation, and documentation of generated information are key to promoting the use of crop diversity in research and crop improvement. This component is mandated with respective crop-based national institutes, AICRIPs, SAUs involved with crop improvement, and NBPGR. Hence most of the information in this regard is scattered and needs to be collated and compiled at the national level, establishing a centralized national information system on crop diversity/genetic resources with linkages between various databases in electronic mode, should the researchers want access to the original source. This will ensure easy access to key information and accelerate the use of genetic diversity in crop improvement. Also, still, a large proportion of germplasm is to be properly characterized and/or evaluated, discerning their potential value in major crops, whereas the minor and underutilized crops have often been left neglected, demanding to strengthen evaluation efforts. To ensure reliability/stability of data produced and to facilitate wider and effective use, evaluation of crop diversity in the region of its origin (avoiding gene silencing effect) and multilocation evaluation under network mode (to understand adaptability) can be important strategies. Considering the evolution of new challenges due to climate change and diversification of market demand, development and standardization of screening methodologies under internationally acceptable scales are required for evaluation of crop genetic diversity, particularly against the upcoming biotic and abiotic stresses and nutritional traits, in search of the desirable gene(s)/sources. This would need strengthening of linkages between various stakeholders, including conservationists and other researchers, particularly breeders and biotechnologists both at the national and global level.

The major thrust in crop improvement programs is currently emphasizing precise breeding incorporating specific genes (traits), such as tolerance/resistance to abiotic and biotic stresses arising due to climatic change, nutrition as per market demand, input-use efficiency, restructuring plant types, physiological efficiency, yield stability, short duration, etc. Therefore, it is equally important to evaluate the germplasm for these parameters in a multidisciplinary mode to identify trait/gene/alleles of interest. This process needs to be strengthened with the integration of genomics for discerning uniqueness at the molecular (DNA) level, to facilitate the identification of molecular markers tightly linked to specific traits to promote marker-assisted selection (MAS) to accelerate the process of gene introgression.

For exploitation of wild species, which many times are the only source of required traits, their characterization and evaluation using appropriate descriptors would be a prerequisite. This may need the development of desired internationally accepted descriptors and codes. It may be followed by biosystematics studies to trace phylogenetic relationships between wild relatives and cultivated species. This would help identification of appropriate breeding strategy for introgression of desirable genes and initiation of a pre-breeding program using both conventional and biotechnological tools to bring wild relative genes into a conventionally usable form of cultigens.

There is a need to recognize that recombinant DNA biotechnology offers opportunities for the transfer of desirable genes across taxonomic boundaries. The identification of desirable accessions (phenotypes) must lead to the identification of gene (s) conferring desirable traits, to enable the direction of efforts on sequencing and isolation of such genes to enable their utilization using biotechnological tools.

11.3.4 Use of Crop Diversity in Crop Improvement/National Food Security

11.3.4.1 Status

Systematic scientific efforts to improve the genetic potential of major Indian crops using both indigenous and exotic crop diversity in India were initiated in 1905 at the Imperial/Indian Agricultural Research Institute, Pusa, Bihar. These were later strengthened with the establishment of necessary institutions over time and international collaboration with both national (USDA) and international programs (FAO, CGIAR, IARCs). These efforts mainly focused on crop improvement for increasing productivity and national production to provide food and nutritional security. They can be classified into (a) the pre-Green Revolution era (1905–1965), which saw the introduction, adaptation, and selection involving the application of Mendelian Laws; (b) the Green Revolution era (1965–1985), the introduction of photo-insensitive, semi-dwarf, high-yielding wheat and rice genotypes/varieties responsive to high input and establishment of a comprehensive seed system, accelerating crop productivity and national production, providing food security; and (c) the post-Green Revolution era (1985 onward) strengthening cultigens with resistance to biotic and abiotic stresses, the main yield-reducing factors, exploiting both indigenous and exotic desirable crop diversity, successful development and use of hybrid technology in more and more crops, including self-pollinated crops, application of advanced genetic principles and molecular breeding, and harmonization of crops diversity with climate change for greater resilience and sustainability. The initial era concentrated on staple food crops, such as wheat, rice, maize, sorghum, and pearl millet, and later extended to grain legumes, oilseeds, and horticulture crops (Singh 1995; Singh et al. 2016).

In the case of wheat, genes for rust resistance from *Khapli* (emmer) were used in breeding for rust resistance. In rice, a coordinated *indica* × *japonica* hybridization project was initiated by the FAO at the Central Rice Research Institute (CRRI), Cuttack, in 1950 to combine high nitrogen response and yield potential with insect and pest resistance into *indica* background (Parthasarathy 1954; Richharia and Misro 1959). On the other hand, in cross-pollinated crops, maize, pearl millet, and sorghum had increased productivity with the application of hybrid technology by establishing and hybridizing pure lines to produce uniform hybrids. This was further extended by developing cytoplasmic male-sterile (CMS) lines for the production of cost-effective hybrid seeds on a large scale exploiting heterosis gains. These strategies were extended to other crop groups, such as grain legumes, oilseeds, horticulture crops, etc. enhancing the genetic diversity and developing new cultigens with greater resilience to stresses and increased productivity.

Crop diversity originating from India has helped the international community with access and use of some useful diversity in crop improvement programs. For example, the rice variety IR-8 developed by IRRI, occupying 80% of areas under dwarf varieties in Asia, has genes from the Indian variety Latisail. In wheat, Kharchia local/Kharchia 65 and Hind 62 have been the source of genes conferring salt tolerance and heat tolerance respectively, while NP-4 of grain quality. Similarly, in pigeon pea, Brisa Arhar, Pragati, and Maruti are sources of wilt resistance; Pant A3 is the source of *Phytophthora* blight resistance; ICP 11384 is the source for sterility mosaic; ICP 332 is the source of pod borer resistance; MA2, MA3, and Gwalior 3 are sources of pod fly resistance; and ICP 7035 vegetable type is the source of combined resistance to wilt and sterility mosaic and ICP 6997 for sterility mosaic and yield, while ICP 6393 and ICP 7018 are in the parentage of several cultivars. Whereas, in sugarcane CO 213, 290, 312, 313, and 475 are the sources of earliness.

The wild relatives of crops, such as *Oryza rufipogon*, *O. longistaminata*, and *O. glaberrima*, in rice have been the sources of resistance to biotic and abiotic stresses (Brar 2005). *Oryza rufipogon* and *O. perennis* have been the sources of cytoplasmic male sterility in the case of rice (Dalmacio et al. 1995; Xian-Hua et al. 2013), while *Cajanus scarabaeoides* and *C. cajanifolius* in the case of pigeon pea (Tikka et al. 1997; Saxena et al. 2005). Among vegetables, *Cucumis hardwickii* has been the source of downy mildew resistance.

Consequent to these efforts, using the desirable crop diversity through conventional breeding, genetic gains were achieved enhancing the crop yield levels in the case of cereals, particularly rice and wheat. This resulted in enhancing cereal production from 50 million tons in 1950–1951 to nearly 250 million tons in 2013–2014. However, gains in pulses and oilseeds have been slow (Fig. 11.3). Therefore, extra efforts are needed, including using molecular breeding to increase productivity further to meet the demand of the ever-growing Indian population. This is a challenge.

In recent times, genomics has helped in the decoding of genomes in several major crops, while functional genomics associates useful traits/genes with DNA sequence variation (markers) and altered phenotype for important traits. This has helped in the

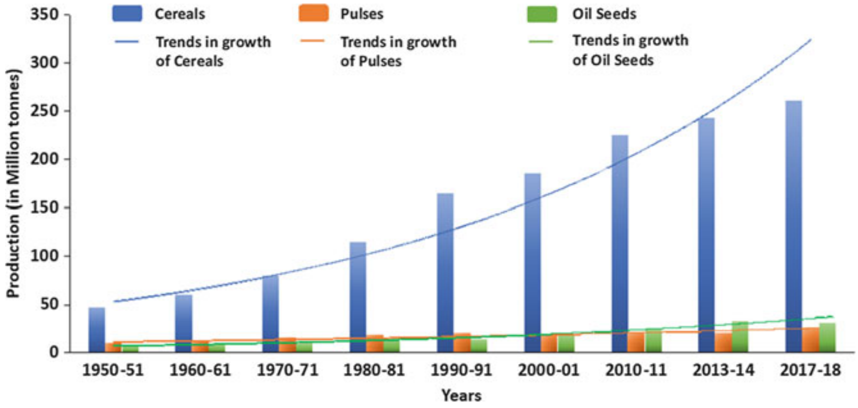

Fig. 11.3 Genetic/yield gains achieved in productivity of cereals, grain legumes, and oilseed achieved between 1950–1951 and 2017–2018 due to crop improvement using crop diversity. (Source: Updated on Singh et al. 2016)

improvement of productivity, quality, and resistance to biotic and abiotic stresses in the crops with higher precision in a reduced timeframe. Molecular marker-assisted selection (MAS) is gaining momentum in transferring simply inherited traits with minimum linkage drag and maximum recurrent parent genome recovery. Moreover, combining phenotype-based selection with genotype-based selection would yield potential results. MAS has now become a standard selection tool in the many crop improvement programs with success stories for transferring desired traits in many crops, such as rice, maize, wheat, chickpea, soybean, etc. (Singh et al. 2016).

11.3.4.2 Challenges and Solution

Despite successful collection and conservation of crop diversity, the use in crop improvement did not commensurate with the efforts spent on collection and conservation. This has been a global phenomenon as Duvick (1984) reported the use of only around 1.5% of the total collections in the USA (across crops), and the same is true for India. This must change with the generation of more and more information about the potential value of collected crop diversity to promote greater use in genetic improvement of crop species for increasing productivity.

The success of crop improvement programs depends largely on the extent and access to information about genetic variability to the researchers, particularly for genes conferring desirable traits. Therefore, after identification of resources their documentation into user-friendly databases, their linking with various national databases, and establishing a national information system with total information, maybe the initial steps. These databases should be compatible with international information systems developed by FAO and CBD, harnessing the benefits of the provisions of various international conventions, treaties, and initiatives.

Many times the desirable genetic diversity is not available in the primary gene pool of cultivated species or if available is placed in the very poor agronomic background or most often available in ancestral or distantly related wild relatives of crop species, because of their evolution fighting against adverse climate/stresses and evolving genes conferring greater resilience. However, this crop diversity may not be accessible for genetic introgression by conventional breeding. In such a situation, pre-breeding efforts using conventional cytogenetic and/or biotechnological manipulations may be required to bring desirable genes into a usable form of cultivated species. Therefore, there is a need for establishing pre-breeding programs for the incorporation of desirable crop (genetic) diversity from distant relatives to strengthen improvement efforts.

In this regard, the advancement in recombinant DNA technology permitting identification, isolation, and insertion of naturally occurring target DNA sequences associated with desirable variability offers opportunities for incorporation of desirable diversity into cultigens in a more precise and directed manner through *cisgenesis*, which can be a useful option. This will help overcome the problems of genetic drag and avoid biosafety concerns raised in the case of transgenesis. The use of this approach may also help in reducing the time for engineering new cultivars to meet the challenges of climate change and market demand.

11.4 International Cooperation

No nation is self-sufficient in crop diversity for any crop. Adaptation and cultivation of crops under diverse agroclimatic conditions across the globe has led to the origin of a large amount of genetic diversity for different traits related to productivity and resilience against stresses. Therefore, there is an interdependence for the availability of useful diversity in search of conferring genes/alleles. The Fifth Report of The Intergovernmental Panel on Climate Change (IPCC) (Vermeulen 2014) has emphasized the centrality of plant breeding for developing climate-smart crop varieties endowed with genes resistant/tolerant to abiotic and biotic stresses. It also emphasizes the mitigation aspects to minimize the rate of climate change and its footprint on biodiversity (genetic erosion) and habitat. Hence, international cooperation is required for access to useful diversity. The international community has evolved several international conventions, treaties, and agreements to facilitate access to useful crop diversity as per the provisions enshrined in respective agreements over space and time.

Considering this scenario, India has been a signatory to all such agreements and conventions starting from 1983, when the FAO International Undertaking (IU) on Plant Genetic Resources pronounced the genetic resources as "common heritage" of mankind, encouraging free exchange. In 1992, the UN Biological Diversity Convention (UNCED/CBD 1992) declared that the plant genetic resources are the "sovereign property of the country in whose territory they are found," and access to them is not "free" and should be negotiated between the donor and the recipient country. In 2004, an International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA-FAO 2011) was brought out by the FAO internalizing the CBD provisions (ITPGRFA 2011) covering 64 food and agriculture crop species (Annex I) that are important to meet 80% demand for food security. Further, on 29 October 2010, the Nagoya Protocol came into existence as supplementary of CBD provisions to promote sharing the benefit arising from the utilization of genetic resources of remaining biodiversity in a fair and equitable manner, thereby contributing to encouraging conservation and sustainable use of biodiversity. The recent treaties recognize the contributions of farmers and local communities and Farmers' Rights and Indigenous Technological Knowledge (ITK), and hence they are being protected with appropriate provisions ensuring fair and equitable sharing of benefits accruing from the commercialization of the products developed with their use.

The Global Crop Diversity Trust (a foundation for food security) was established in 2004 jointly by FAO and Biodiversity International (CGIAR) to ensure the conservation and availability of plant genetic resources for food and agriculture (GCDT 2006). The Trust has been promoting the use of a competitive grant scheme for germplasm evaluation, strengthening the data management system for gene banks, and creating a searchable global accession level PGRFA information system. India being a major partner must take advantage of and contribute to such initiatives.

India has paid attention to the necessity of conservation and utilization of its agrobiodiversity and biodiversity, by establishing the national Protection of Plant Variety and Farmers Right Authority (PPV&FRA 2001) to safeguard farmers' and breeders' rights with the registration of their varieties and ensuring fair and equitable benefit sharing in case of commercialization of products developed using them. Similarly, to address the issues related to the rest of the national biodiversity, the Biological Diversity Act (BDA 2002) has been established to regulate access to genetic resources and ensure fair and equitable benefit sharing accrued from the commercialization of the product developed using them and the associated Indigenous Traditional Knowledge (ITK). National Biodiversity Authority (NBA) works as a national focal point (NFPs) and competent national authority (CAN) to serve as a contact point for information, grant access, and cooperate on issues for compliance of the provisions of Nagoya Protocol. However, greater efforts are required for active participation and availing the benefit of the provisions encompassed in the various agreements.

11.5 Policy Solution and Recommendations

Considering the above perspective/scenario of crop diversity following recommendation/policy decision may be considered for effective and efficient management of national crop diversity, promoting conservation and use:

- Only pointed and rescue collections of crop diversity (plant genetic resources, PGR).

- Recognizing the potential value of crop wild relatives and poor representation in germplasm collections (international germplasm has only 2–6%; Maxted and Kell 2009); further efforts be made for their collection and conservation for detailed study as alternative genetic resources.
- Integration of genomics in the characterization of collections for identification of duplicates and distinctiveness to avoid redundancy and facilitate conservation of unique collections.
- Further evaluation of assembled crop diversity (PGR) in addition to common stresses/traits, for traits needed as per changing climate (temperature, drought, etc.) and market forces (nutrition) to add value and encourage conservation.
- Advantage must be taken of bioinformatics/computer science in developing a national information system on crop diversity/PGR, linked to national and global databases.
- Development and regular updating of core and mini-core collection sets, with the inclusion of desirable qualitative (rare) and quantitative (allelic) diversity to keep them dynamic and facilitate cost-effective management and use.
- Crop diversity being the national heritage must be shared unrestricted (without bindings) with the distribution of desirable PGR within the national agricultural research system to facilitate greater use in crop improvement.
- Single window system for distribution of base and active PGR through NBPGR to establish an information clearing mechanism about conservation and use.
- The gene banks and active germplasm sites should be appraised based on a number of accessions distributed for research and crop improvement to keep them relevant for national use.

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Chapter 12
Biodiversity of Agriculturally Important Insects: Status, Issues, and Challenges

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12.1 Introduction

The services provided by biodiversity to agriculture through pollination and pest control are valued at approx. US$ 57 billion per year (Losey and Vaughan 2006). Ecosystem functioning increasingly depends on diversity, especially in the case of natural enemy diversity for pest control. In the 1980s, ecologists viewed the shrinking biodiversity as an alarming situation (Ehrlich and Ehrlich 1981). Field studies indicated that when the number of species and functional diversity of natural enemies increases, there is a significant increase in pest suppression (Evans 2016). An insect pest, a plant disease, or a weed exists in nature along with a pool of natural enemies. The major focus in applied biological control should be to select an appropriate species or combination of species from this pool and to work on a strategy to bring about the desired level of pest or disease suppression with minimal impact on non-target species. Biological control attempts have been through the importation of exotic natural enemies and also through the conservation or augmentation of the potential indigenous biological control agents. Of more than one-and-half million insect species that occur in this world, only about 1.0% have attained the status of pests. Many species which have pestilent potential remain at low levels because of the perpetual regulatory action exerted on them by their natural enemies. Hence, for the management of some of our major pests, diseases, and weeds, it is important to restore the natural balance through purposeful human intervention. For tackling outbreaks of indigenous pests, the management approach could be through augmentation or conservation of indigenous natural enemies. When we are targeting invasive species, we generally resort to classical biological control. However, there are instances where invasives have been tackled through conservation or augmentation biocontrol. In order to conserve or utilize the beneficial insects, it is important

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to survey the different agroecosystems, search for beneficial pollinators and natural enemies, identify them, and document them. Measurement of insect diversity is of prime importance as this would enable us to understand the ecological role played by each species in a particular ecosystem.

12.2 Diversity Indices to Measure Insect Diversity

Insects are important because of their huge diversity, the ecological role they play, and their influence on agriculture. Estimates of total number of insect species in a given location at a given time are very important in order to measure insect diversity. For measuring this biodiversity, effective sampling and estimation procedures are required.

12.2.1 Measuring Biodiversity over Spatial Scales Includes Three Types of Diversity

(a) Diversity of insect species within a habitat or particular area, known as α diversity.
(b) Diversity of insect species compared between habitats at the ecosystem level, known as β diversity.
(c) Diversity of insect species in different ecosystems within a geographical region or landscape, known as γ diversity (Magurran 2004; Begon et al. 2006).

12.2.2 Species Diversity

The count on the number of insect species is the primary unit to measure either α or β or γ diversity. Species diversity includes species richness and species evenness. Species richness is the number of species present or occurring per sample in a given habitat or ecosystem, while species evenness is the relative abundance of the different species, how evenly the individuals in a community are distributed among the different species (Table 12.1).

Depending on the species richness and evenness, the diversity varies. Though Table 12.1 represents 100 species in each ecosystem indicating equal species richness, the relative abundance of each species depicts that species diversity is high in the grassland ecosystem than the crop ecosystem as the species are evenly distributed in the former and skewed towards beetles and butterflies in latter. So, to quantify the same and present the data with statistical accuracy, certain diversity indices need to be adopted for measuring the species richness and evenness in a given population or community.

Table 12.1 A hypothetical example of insect collections from a grassland and a crop ecosystem

Species of:	Grassland ecosystem	Crop ecosystem
Butterflies	24	21
Beetles	26	51
Dragon flies	17	15
Grasshoppers	18	8
Spiders	15	5
Total	100	100

12.2.3 *Diversity Indices*

Diversity indices focus on the taxa abundance and emphasize either *richness*, towards rare taxa, or dominance, towards abundant taxa (Magurran 1988).

To calculate or assess the species diversity in terms of species richness and evenness within and between the habitats or ecosystems, there are a number of diversity indices (Magurran 2004) as described below:

1. *Shannon-Wiener Index*—The Shannon-Wiener Index (Shannon 1948; Shannon and Wiener 1949) is the most commonly used diversity index in most of the ecological studies. This index considers that individuals are randomly sampled from an infinite population not reflecting the exact sample size and assuming that all taxa are represented in the sample (Peet 1974; Magurran 1988). It is important for the abundant species rather than the rare species in the sample.
2. *Equitability Index*—Equitability Index, i.e. evenness of any two species in a population, is calculated by dividing the Shannon Diversity with the logarithm of the number of taxa. This measures the evenness with which individuals are divided among the taxa present.
3. *Simpson's Index*—Simpson's Index takes into account the number of species as well as the relative abundance, thus addressing both richness and evenness (Simpson 1949). Simpson's Diversity Index includes three closely related indices, viz. Simpson's Index (D), which measures the probability that two randomly selected individuals from a sample belong to the same species; Simpson's Index of Diversity (1-D), which measures the probability that two randomly selected individuals belong to different species; and Simpson's Reciprocal Index is 1/D. Both the Simpson's Index and Simpson's Index of Diversity values range between 0 and 1; in the case of D, a value closer to 0 indicates higher diversity and a value closer to 1 indicates lower diversity, whereas in '1-D', a value closer to 0 indicates lower diversity and value closer to 1 indicates higher diversity. In Simpson's Reciprocal Index, the value starts with 1 and ranges up to the number of species in the sample, and a higher value indicates a greater diversity. Depending upon the sampling size and number, appropriate Simpson's diversity index may be used for the calculation of the diversity.
4. *Pielou's Evenness Index*—Pielou's Evenness Index measures the evenness of individuals among the species. The relative distribution of the species is taken into account and measured (Pielou 1975). The value ranges between 0 and 1, and

Table 12.2 Measuring diversity of beneficial insects: parasitoids and predators

S. no.	Species	Apple orchard	Shannon-Weiner Index			Simpson's Diversity Index	
		Total number	Pi	ln(pi)	pi × ln (pi)	$(n/N)^2$	$n(n-1)$
1.	Coccinellid species (Ladybird beetles)	45	0.45 =45/100	−0.80	−0.36	0.203 $(45/100)^2$	1980 45 × 44
2.	Syrphid species (Hoverflies)	21	0.21 =21/100	−1.56	−0.33	0.044 $(21/100)^2$	420 21 × 20
3.	Ichneumonid wasps (Parasitic tiny wasps)	17	0.17 =17/100	−1.77	−0.30	0.029 $(17/100)^2$	272 17 × 16
4.	Braconid wasps (Parasitic tiny wasps)	10	0.10 =10/100	−2.30	−0.23	0.01 $(10/100)^2$	90 10 × 9
5.	Chrysopid species (Green lacewings)	7	0.07 =7/100	−2.66	−0.19	0.005 $(7/100)^2$	42 7 × 6
	Total	*100*			*−1.41*	*0.291*	*2804*

the evenness increases with the value, where 0 indicates no evenness and 1 indicates complete evenness.

5. *Berger-Parker Index*—The Berger-Parker Index (Berger and Parker 1970) expresses the proportional importance of the most abundant type. This is highly influenced by sample size and richness. The unequal distribution of abundance between species allows the use of the dominance index of Berger-Parker to express the proportion of individuals accounted for by the most abundant species in each site.
6. *Margalef Index*—The species richness index of Margalef Index D (Margalef 1958) is used to calculate the most species-rich sample and is calculated as the species number (S) minus 1 divided by the natural logarithm of the total number of individuals (N).
7. *Menhinick's Index*—Menhinick's Index DMn is complementary to the Margalef Index and used to calculate species richness (Menhinick 1964).

The calculation of diversity indices is explained here with a hypothetical example of insect species (beneficial insects, parasitoids, and predators) collected from an apple orchard through different traps (yellow pan trap, malaise trap), sweep net, and manual scouting. The list of species collected are furnished in Table 12.2 along with the calculation of various diversity indices to assess the species richness and evenness.

All diversity and evenness indices are dependent on the relative abundance of species. In a given location of an apple orchard, the species richness is 5 with high species diversity as evidenced by the Shannon-Wiener Index (1.41) and Simpson's

Table 12.3 Calculation of other diversity indices

S. no.	Indices		Formula	Value
1.	Shannon-Wiener Index, H′	$S = 5$		1.41
2.	Evenness, E	Hmax = ln(5) = 1.61	=1.41/1.61	0.88
	Simpson's Index			
3.	D	$n(n-1) = 2804$ $N(N-1) = 100 \times 99 = 9900$	=2804/ 9900	0.283
4.	1-D		=1–0.283	0.717
5.	Simpson's Reciprocal Index 1/D		=1/0.283	3.53
6.	Pielou's Evenness Index, J	1.41/ln(5)	=1.41/1.61	0.88
7.	Berger Parker Index 1/D		=45/100	0.45
8.	Margalef Index, D	(5–1)/ln(100)	4/4.61	0.87
9.	Menhinick's Index, Dmn	5/√100	5/10	0.5

Index (1-D) (0.717). The species evenness is also high as evidenced by equitability and Pielou's Evenness Index (0.88). The Berger-Parker Index represents the most dominant species of the community, and in this hypothetical example, the coccinellid species with a value of 0.45 is the dominant species (Tables 12.2 and 12.3).

The different measures of diversity appear sensitive to either the commonest or the rarest species. The indices usually depend on sample size, sampling location, the spatio-temporal structure of the community, and sampling error, so, depending upon the sample assemblages, the appropriate diversity indices may be used taking into account the possibilities and limitations of diversity and evenness indices. Several indices may be used in tandem to compare different assemblages to minimize the errors if any. These indices can be used in a study of hierarchical and/or spatio-temporal components of diversity (Tables 12.2 and 12.3).

12.3 The Diversity of Beneficial Insects

There are two key gaps in understanding and utilizing the positive aspects of insect diversity: general neglect of insects in biodiversity research and an overemphasis on their negative impacts in all other biological research areas. Insects have been looked at more often as pests than as beneficial organisms by a majority of the stakeholders. In this chapter, we are focusing on three groups of beneficial insects—parasitoids, predators, and pollinators.

12.3.1 Challenges in Insect Diversity Documentation

There are millions of species of insects, mites, and spiders still undescribed, and hence, systematics has a larger and more prominent role to play in unearthing the species richness of various ecosystems. However, there are far too less taxonomists to do the job. The taxonomic impediments like limited access to taxonomic literature, lack of expertise, and poor international networking do impact our ability to identify, document, conserve, and utilize insect biodiversity. Internationally the accepted taxonomic practice involves the exchange of dead specimens between taxonomists for comparison with types housed in select museums (situated in India and various parts of the world), which is imperative to arrive at the correct identity of insect species for both new and known species. For strengthening the area of expertise in specific groups of insects, international networking is very important. Indian museums hold many specimens of insect and other arthropod species awaiting discovery and description. A set of streamlined procedures are now in place at the National Bureau and Agricultural Insect Resources for the exchange of dead specimens with international taxonomists in 18 countries, leading to the development of reference collections in specific groups, thus strengthening the documentation of insect biodiversity.

12.4 Biodiversity and Significance of Parasitoids in Indian Agroecosystems

Hymenoptera at present is known to hold 116,861 species described globally (Storks 2018). The parasitic Hymenoptera is the largest group of Hymenoptera with major entomophagous species associated with various pests of agroecosystems. The major parasitic and predatory superfamilies involved are as follows: Apoidea, Ceraphronoidea, Chalcidoidea, Chrysidoidea, Cynipoidea, Diaprioidea, Evanioidea, Ichneumonoidea, Megalyroidea, Orrusoidea, Proctrutropoidea, Platygastroidea, Stephanoidea, Trigonalioidea, and Vespoidea. The prominent examples are dealt below (Plate 12.1).

12.4.1 Superfamily Ichneumonoidea

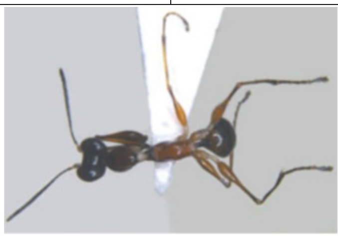
The superfamily Ichneumonoidea includes two families, viz. Braconidae and Ichneumonidae, and both these play an important role in maintaining pest populations in the agroecosystems. Most ichneumons are parasitoids of Lepidoptera, Hymenoptera, Diptera, Coleoptera, Neuroptera, and Mecoptera, as well as spiders. There are a total 43 subfamilies under the family Braconidae (Quicke 2015). The key subfamilies in Indian agroecosystems include the following: Agathidinae, Alysiinae, Aphidiinae, Braconinae, Cheloninae, Doryctinae, Euphorinae, Helconinae, Microgastrinae, Opiinae, and Rogadinae (van Achterberg 1993; Yu et al. 2012) (Table 12.4).

An ichneumonoid

A chalcidoid

A platygastroid

A diapriid



A chrysidoid

Plate 12.1 Examples of parasitioids

12.4.2 Family Ichneumonidae

The family Ichneumonidae presently has ten agriculturally important subfamilies with major parasitoids of some of the important crop pests in India: Anomaloninae, Banchinae, Campopleginae, Cremastinae, Cryptinae, Ctenopelmatinae, Ichneumoninae, Mesochorinae, Ophioninae, and Pimplinae (Table 12.5).

Table 12.4 Common species of braconid parasitoids associated with agriculturally important pests

S. no.	Species	Subfamily	Host range
1.	*Aleiodes* sp.	Rogadinae	Parasitic on many lepidopterans
2.	*Apanteles galleriae* Wilkinson	Microgastrinae	Greater wax moth *Galleria mellonella* L. (Pyralidae)
3.	*Apanteles machaeralis* Wilkinson	Microgastrinae	Teak skeletonizer *Eutectona machaeralis* (Walker) (Crambidae) on *Tectona grandis* L.
4.	*Apanteles phycodis* Viereck	Microgastrinae	*Argina syringa* Cramer (Erebidae: Arctiinae)
5.	*Apanteles taragamae* Viereck	Microgastrinae	Coconut black-headed caterpillar *Opisina arenosella* Walker (Oecophoridae) on coconut.
6.	*Aphidius colemani* Viereck	Aphidiinae	A common parasitoid of several species of economically important aphid pests like *Myzus persicae*, *Aphis gossypii*, etc.
7.	*Bassus relativus* (Bhat and Gupta)	Agathidinae	Legume pod borer *Maruca vitrata* (Fabricius) (Lepidoptera: Crambidae)
8.	*Bracon brevicornis* (*Habrobracon*) (Wesmael)	Braconinae	An extremely polyphagous ectoparasitoid attacking Crambidae and Pyralidae in stored products and in the field; in the field, other lepidopterous families may also be attacked. Important hosts include *Opisina arenosella* (Walker), Spotted stalk borer *Chilo partellus* (Swinhoe), Pink boll worm *Pectinophora gossypiella* (Saunders); rice moth *Corcyra cephalonica* (Stainton). (factitious laboratory host, used widely for mass rearing of parasitoids and predators in Indian insectaries)
9.	*Bracon hebetor* (*Habrobracon*)	Braconinae	An extremely polyphagous ectoparasitoid, attacking Crambidae and Pyralidae. It is a major parasitoid of the rice moth
10.	*Chelonus blackburni* Cameron	Cheloninae	Egg-larval parasitoid of several lepidopterous pests like potato tuber moth, *Phthorimaea operculella*, Cotton bollworms, *Hellula undalis*, *Plutella xylostella*, etc.
11.	*Chelonus formosanus* Sonan	Cheloninae	*Chelonus formosanus* is a parthenogenetic egg-larval parasitoid of *Spodoptera litura* (F.) on cotton and other host plants and the fall armyworm *Spodoptera frugiperda* (J. E. Smith) on maize
12.	*Cotesia erionotae* (Wilkinson)	Microgastrinae	Parasitoid of *Udaspes folus* (Cramer) (Hesperiidae) on *Zingiber zerumbet* (L.) Smith
13.	*Cotesia flavipes* Cameron	Microgastrinae	Parasitoid of *Chilo partellus* (Swinhoe) (Crambidae) on maize

(continued)

Table 12.4 (continued)

S. no.	Species	Subfamily	Host range
14.	*Cotesia glomerata* (Linnaeus)	Microgastrinae	Parasitoid of *Pieris brassicae* L. (Pieridae) on *Brassica oleracea* L.
15.	*Cotesia ruficrus* (Haliday)	Microgastrinae	*Spodoptera* spp. (Noctuidae) and *Spodoptera frugiperda* on maize
16.	*Cotesia ruidus* Wilkinson	Microgastrinae	Teak skeletonizer *Eutectona machaeralis* (Walker) (Crambidae)
17.	*Cotesia vestalis* (Haliday)	Microgastrinae	Diamondback moth *Plutella xylostella* (L.) (Plutellidae) on cabbage
18.	*Diaeretiella rapae* (McIntosh)	Aphiidiinae	Solitary endoparasitoid of several species of aphids.
19.	*Distatrix papilionis* (Viereck)	Microgastrinae	Lime swallowtail butterfly *Papilio demoleus* L. (Papilionidae) on *Citrus aurantiifolia*(Christm.) Swingle
20.	*Dolichogenidea cinnarae* Gupta, Lokhande & Soman	Microgastrinae	Rice swift *Borbo cinnara* (Wallace) (Hesperiidae)
21.	*Dolichogenidea stantoni* (Ashmead)	Microgastrinae	*Parotis marginata* (Hampson) (Crambidae)
22.	*Euscelinus* sp.	Doryctinae	Beetle- *Sinoxylon* sp. (Bostrichidae)
23.	*Fornicia ceylonica* Wilkinson	Microgastrinae	Moth *Spatulifimbria castaneiceps* Hampson (Limacodidae) on castor.
24.	*Glyptapanteles aristolochiae* (Wilkinson)	Microgastrinae	*Pachliopta hector* (Linnaeus) (Papilionidae)
25.	*Glyptapanteles creatonoti* Viereck	Microgastrinae	Red hairy caterpillar *Amsacta albistriga* (Walker) (Erebidae: Arctiinae) on groundnut.
26.	*Glyptapanteles hypermnestrae* Gupta & Pereira	Microgastrinae	Common palmfly *Elymnias hypermnestra* (Linnaeus) (Nymphalidae) on coconut.
27.	*Glyptapanteles obliquae* (Wilkinson)	Microgastrinae	Bihar hairy caterpillar *Spilosoma obliqua* Walker (Erebidae: Arctiinae)
28.	*Glyptapanteles obliquae* (Wilkinson)	Microgastrinae	Erebidae: Arctiinae
29.	*Glyptapanteles spodopterae* Ahmad	Microgastrinae	Tobacco cutworm *Spodoptera litura* Fab. (Noctuidae)
30.	*Meteoridea hutsoni* (Nixon)	Meteorideinae	Coconut blackheaded caterpillar, *Opisina arenosella* (Walker)
31.	*Microplitis carinicollis* (Cameron)	Microgastrinae	Yellow hairy caterpillar *Psalis pennatula* (Fab.) (Erebidae: Lymantriinae)
32.	*Microplitis demolitor* Wilkinson	Microgastrinae	Cotton bollworm *Helicoverpa armigera* (Hubner) (Noctuidae)

(continued)

Table 12.4 (continued)

S. no.	Species	Subfamily	Host range
33.	*Microplitis indicus* Marsh	Microgastrinae	*Helicoverpa* sp. and *Helicoverpa assulta* (Guenee) (Noctuidae)
34.	*Microplitis maculipennis* (Szepligeti)	Microgastrinae	Moth *Acanthodelta janata* L. (Erebidae) on castor
35.	*Microplitis manilae* Ashmead	Microgastrinae	*Spodoptera* sp. (Noctuidae)
36.	*Microplitis prodeniae* Rao & Kurian	Microgastrinae	Moth *Spodoptera litura* (Fabricius) (Noctuidae) on *Amaranthus* sp.
37.	*Microplitis spodopterae* Rao & Kurian	Microgastrinae	Moth *Spodoptera mauritia* (Boisduval) (Noctuidae) on *Trigonella foenum-graecum* L.
38.	*Myosoma chinensis* (Szepligeti)	Braconinae	Commonly collected in association with graminaceous stem borers on rice, sorghum, maize, and sugarcane, particularly, *Chilo partellus* (Swinhoe), and other *Chilo* spp., *Scirpophaga excerptalis*, and *Sesamia inferens*
39.	*Parallorhogas pallidiceps* (Perkins)	Doryctinae	Common parasitoid of larvae of cerambycid beetles (Coleoptera)
40.	*Phanerotoma* sp.	Cheloninae	Lepidopteran parasitoid
41.	*Stenobracon* (*Stenobracon*) *nicevillei* (Bingham)	Braconinae	Solitary larval parasitoid of several graminaceous borers such as *Chilo partellus* Swinhoe, *C. infuscatellus* Snellen, *C. sacchariphagus indicus* (Kapur), *C. auricilius* Dudgeon, *C. suppressalis* (Walker), *Scirpophaga excerptalis* (Walker), *S. incertulas* (Walker), *S. innotata* (Walker), *S. nivella* (F.), and *Sesamia inferens* (Walker) on rice, sugar-cane, sorghum and maize
42.	*Stenobracon* (*Stenobracon*) *deesae* (Cameron)	Braconinae	Solitary larval ectoparasitoid of graminaceous stem borers such as *Chilo partellus* Swinhoe, *C. infuscatellus* Snellen, *C. sacchariphagus* *C. indicus* (Kapur), *C. auricilius* Dudgeon, *C. suppressalis* (Walker), *C. tumidicostalis* (Hampson), *Scirpophaga excerptalis* (Walker), *S. incertulas* (Walker), *S. innotata* (Walker), *S. nivella* (F.),

(continued)

Table 12.4 (continued)

S. no.	Species	Subfamily	Host range
			Acigona steniellus (Hampson) and *Sesamia inferens* (Walker) on rice, sugarcane, sorghum, and maize

12.4.3 Superfamily Chalcidoidea

The superfamily is presently divided into 19 families. Currently, the largest family is the Eulophidae followed closely by the Encyrtidae and Pteromalidae. The large majority of chalcid species are primary parasitoids of other insects and arachnids and as such, they are important for regulating arthropod populations. As of now, 3121 species are reported from India from 18 families of chalcid wasps: Agaonidae, Aphelinidae, Chalcididae, Encyrtidae, Eucharitidae, Eulophidae, Eupelmidae, Eurytomidae, Leucospidae, Mymaridae, Ormyridae, Perilampidae, Pteromalidae, Signiphoridae, Tanaostigmatidae, Tetracampidae, Torymidae, and Trichogrammatidae (Noyes 2020) (Table 12.6).

12.4.4 Superfamily Platygastroidea

Platygastroidea is the third-largest superfamily in Hymenoptera with 5800 species under 270 genera described worldwide. In India, 65 genera with 340 species are described so far. Family Platygastridae has five subfamilies, viz. Teleasinae, Telenominae, Scelioninae, Sceliotrachelinae, and Platygastrinae. The first three subfamilies are exclusively egg parasitoids, parasitizing the eggs of Lepidoptera, Heteroptera, Orthoptera, Embioptera, Coleoptera, Odonata, Mantodea, and spiders. Platygastrinae is known to parasitize the eggs and early larval stages of gall midges while Sceliotrachlinae are parasitoids of eggs of Coleoptera such as weevils, chysomelids, and longicorn beetles in addition to larvae of whiteflies (Aleyrodidae), aphids, planthoppers, and mealybugs (Pseudococcidae). As these are generally egg parasitoids, they are potential biological control agents. As they have high host searching ability and high reproductive rates, and due to absence of hyperparasitism, they are good candidates for biological control in the field. *Trissolcus basalis* was used against *Nezara virudula* (Pentatomidae) on vegetables which gave complete control and is one of the landmark examples in biological control. Species of *Telenomus*, *Gryon*, and *Trissolcus* are the promising egg parasitoids associated with eggs of many pests.

Table 12.5 Agriculturally important subfamilies of Ichneumonidae reported from India with common examples of agriculturally important parasitoids

S #	Species	Subfamily	Host range
1.	*Campoletis chlorideae* Uchida	Campopleginae	Larval parasitoid of Noctuidae, particularly the cotton bollworm *Helicoverpa armigera* (Huebner), tobacoo cutworm *Spodoptera litura* (F.), and the fall armyworm *S. frugiperda* on maize
2.	*Casinaria ajanta* Maheshwary & Gupta	Campopleginae	Parasite of *Ampittia dioscorides* (Fabricius) (Lepidoptera: Hesperiidae) and parasite of *Parnara* sp. (Lepidoptera: Hesperiidae)
3.	*Charops bicolor* (Szépligeti)	Campopleginae	Genus *Charops* parasitizes larvae of lepidopterous stem borers. Most species are specialized parasitoids of mostly noctuid larvae as koinobiont endoparasitoids. *Charops bicolor* is commonly collected in association with stem borers on rice. Recorded hosts include many lepidopteran pests—*Naranga aenescens*, *N. diffusa*, *Anomis flava*, *Pelopidas mathias*, *Psalis pennatula*, *Leucania loreyi*, *Spodoptera mauritia*, *Scirpophaga incertulas*
4.	*Diplazon* spp.	Diplazontinae	Species of the genus *Diplazon* are parasitoids of hoverflies (Diptera: Syrphidae). Two species, *D. laetatorius* and *D. orientalis*, are commonly collected in India
5.	*Eriborus argenteopilosus* (Cameron)	Campopleginae	Larval endoparasitoid of several major noctuid pests such as *Spodoptera litura* (F.), the cotton bollworm *Helicoverpa armigera* (Huebner), brinjal fruit and shoot borer *Leucinodes orbonalis* Guenee, and *Crocidolomia pavonana* (F.) (=*C. binotalis* Zeller) on various crops
6.	*Eriborus trochanteratus* (Morley)	Campopleginae	Potato tuber moth *Phthorimaea operculella* Zeller, yellow peach moth *Dichocrocis punctiferalis* (Guenee), the cotton bollworm *Helicoverpa armigera* (Huebner).
7.	*Gelis* sp.	Cryptinae	Associated with spider eggs
8.	*Ischnojoppa luteator* (Fabricius)	Ichneumoninae	Species of *Ischnojoppa* are reported as larval and pupal endoparasitoids of lepidopterous stem borers. The recorded hosts include *Scirpophaga incertulas* (Walker), *S. innotata* (Walker), *S. nivella* (F.), *Chilo polychrysus* (Meyrick), *Chilo* sp., *Cnaphalocrocis medinalis* (Guenee), *Pelopidas mathias* (F.), and *Borbo cinnara* Wallace. Commonly collected from rice ecosystem
9.	*Isotima javensis* (Rohwer)	Cryptinae	Larval parasitoid of *Scirpophaga* spp. occurring on sugarcane and rice
10.	*Leptobatopsis indica* (Cameron)	Banchinae	Often associated with the common straight swift hesperiid *Parnara guttata* (Bremer & Grey)

(continued)

Table 12.5 (continued)

S #	Species	Subfamily	Host range
11.	*Mesochorus* spp.	Mesochorinae	*Mesochorus* spp. is obligate, internal, larval hyperparasitoids of braconids and ichneumonids
12.	*Trathala flavoorbitalis* (Cameron 1907)	Cremastinae	The most common host species reported are borers, namely, *Maruca vitrata*, *Chilo partellus* (Swinhoe), *Chilo suppressalis* Walker, *Dichocrocis punctiferalis* (Swinhoe), *Diaphania indica* (Saunders), *Etiella zinckenella* (Treitschke), *Scirpophaga incertulas* Walker, *Spodoptera exigua* (Huebner), and *Sesamia inferens* (Walker)
13.	*Xanthopimpla stemmator* (Thunberg)	Pimplinae	The species of *Xanthopimpla* are important parasitoids of lepidopterous stem borers of cereals, sugarcane, and sometimes, other crops

12.4.5 Superfamily Diaprioidea

Diapriidae (Hymenoptera: Diaprioidea) is a diverse group of parasitic wasps having a wide distribution globally. They are primarily solitary or gregarious endoparasitoids of dipteran larvae and pupae. Approximately 4000 species of diapriids are estimated to occur in the world, but only less than half of these have been formally described. From India, two subfamilies, Belytinae and Diapriinae, with 85 species in 19 genera are known. *Trichopria* sp. parasitic on dipterous hosts can be mass-produced and used in the biological control of Indian Uzi fly, *Exorista bombycis* (Diptera: Tachinidae).

12.4.6 Superfamily Chrysidoidea

The superfamily Chrysidoidea is a very large cosmopolitan group with some 6000 described species. The families include Bethylidae, Chrysididae, Dryinidae, and four small, rare families (Embolemidae, Plumariidae, Sclerogibbidae, and Scolebythidae). *Goniozus nephantidis* (Muesebeck) (Bethylidae) a gregarious larval ectoparasitoid of the coconut black-headed caterpillar; *Opisina arenosella* Walker (Lepidoptera: Xylorictidae) is apparently host-specific but suspected to have a broader host range. *Gonatopus* spp. (Dryinidae) are commonly associated with leafhoppers in many crops.

Table 12.6 Agriculturally important families of Chalcidoidea reported from India with common examples of agriculturally important parasitoids

S. #	Species	Family	Host range
1.	*Anisopteromalus calandrae* (Howard)	Pteromalidae	Stored grain and general pests viz., *Sitophilus* sp., *Sitophilus oryzae*, *Sitophilus granarius*, *Tribolium castaneum*, *Athesapeuta cyperi*, *Oryzaephilus surinamensis*, *Pempheruls affinis*, *Rhizopertha dominica*, *Cyperus rotundus*, *Callosobruchus* sp., etc.
2.	*Cephaleta brunniventris* Motschulsky	Pteromalidae	Primary hosts are from Coccoidea mainly Coccidae, Cerococcidae, and Pseudococcidae—*Ceroplastes* spp., *Saissetia* spp., *Ferrisia virgata*, and many others also *Asterolecanium* sp. (Asterolecaniidae)
3.	*Aenasius arizonensis* (Girault)	Encyrtidae	Cotton mealy bug—*Phenacoccus solenopsis* Tinsley
4.	*Encarsia guadeloupae* Viggiani	Aphelinidae	Rugose spiraling whitefly—*Aleurodicus rugioperculatus* Martin
5.	*Gyranusoidea tebygi* Noyes	Encyrtidae	Fruit tree mealy bug—*Rastrococcus invadens* Williams
6.	*Anagyrus mangicola* Noyes	Encyrtidae	Fruit tree mealy bug—*Rastrococcus invadens* Williams
7.	*Acerophagus papayae* Noyes & Schauff	Encyrtidae	Solitary endoparasitoid of papaya mealybug - *Paracoccus marginatus* Williams and Granara de Willink
8.	*Anagyrus amnestos* Rameshkumar et al.	Encyrtidae	Madeira mealybug, *Phenacoccus madeirensis* Green
9.	*Trichogramma chilonis* Ishii	Trichogrammatidae	Sugarcane pests, *Chilo infuscatellus*, *Chilo sacchariphagus indicus*, *Chilo auricilius*; cotton pests, *Helicoverpa armigera*, *Pectinophora gossypiella*, and *Earias* spp.; maize stem borer *Chilo partellus*, diamondback moth *Plutella xylostella*, and the fall armyworm *S. frugiperda* on maize
10.	*Trichogramma japonicum* Ashmead	Trichogrammatidae	Top shoot borer of sugarcane *Scirpophaga excerptalis* and paddy stem borer *Scirpophaga incertulas*
11.	*Trichogramma achaeae* Nagaraja & Nagarkatti	Trichogrammatidae	Cotton bollworms and okra borer
12.	*Trichogramma evanescens* Westwood	Trichogrammatidae	Tissue borers of maize and sugarcane

12.4.7 Superfamily Megalyroidea

Megalyridae comprises a family of infrequently collected parasitic wasps with around 49 described species in eight extant genera across the globe, mostly distributed in the tropics and subtropics of the Southern Hemisphere. Information on the biology of parasitic wasps of the megalyrid family is primarily known from a few species of Australian *Megalyra* attacking xylophagous Coleoptera (especially Cerambycidae larvae), and, more rarely, Hymenoptera larvae (Sphecidae) in mud cells on rocks. *Megalyra fasciipennis* Westwood is the only record of Megalyridae species from the Indian subcontinent.

12.5 Diversity of Beneficial Insect Predators

Insect predators form a major group as important biological control agents (Plate 12.2), observed to be more numerous and more widely distributed than the parasites with a greater range of adaptability. They are scattered across various insect orders mainly Odonata, Mantodea, Thysanoptera, Hemiptera, Neuroptera, Coleoptera, Diptera and Lepidoptera. Predators can be broadly categorized as general predators as well as predators of agricultural importance.

		
A dolichopodid	**A hover fly**	**Asopine bug, *Amylotea malabarica***
		
***Zicrona caerulea* feeding on Chrysomelid beetle *Altica* sp.**	**Coccinellid beetle**	**Chrysopid larva feeding on aphids**

Plate 12.2 Examples of predators

12.5.1 General Predators

Dragonflies and damselflies: prey upon mostly small flying insects like midges, mosquitoes, and small moths. The larger dragonflies can capture bees, butterflies, and even other dragonflies.

Asilidae (*robberflies*): attack a wide range of prey including flies, beetles, butterflies, moths, and wasps. It is a good indicator of environmental health. The greater number or diversity of robber flies may indicate good environmental health. The subfamily Asilinae is the megadiverse taxon comprising 183 genera globally (Londt and Dikow 2017).

Dolichopodidae (*Long-legged flies*): predate on mosquitoes and Chironomid midges apart from leafhoppers, psyllids, agormyzids, etc.

Praying Mantids: highly predaceous and feed on a variety of insects. Mukherjee et al. (1995) studied the mantid fauna of India and reported around 162 species in 68 genera.

12.5.2 Predators of Agricultural Importance

Syrphidae (*Hoverflies*): There are about 493 species of syrphids belonging to 107 genera in the Indian sub-region (Ghorpade 2014). They are major predators of aphids and thrips. *Syrphus serarius* Wied. has been recorded from various hill stations in India. *Ischiodon scutellaris* is a common syrphid predator active throughout the year. They feed on aphids in various crops like mustard, cabbage, cotton, and watermelon. The maggots of *Paragus serratus* F. feed on aphids infesting red gram, watermelon, Dolichos lablab, cotton, mustard, and sugarcane.

Anthocoridae: They are commonly called flower bugs or minute pirate bugs. Around 500–600 species of Anthocorids are reported from all over the world (Lattin 2000). The Indian fauna of flower bugs is represented by 73 species belonging to 26 genera (Ballal et al. 2018). They are generalist predators, globally used as efficient biocontrol agents, and also a promising group in the context of Indian agriculture (Ballal and Yamada 2016). The most diverse genera in terms of species are *Orius*, *Anthocoris*, *Physopleurella*, *Xylocoris*, *and Buchananiella*. This group is an important component of predatory fauna found in many agroecosystems. Both nymphs and adults are predators of small arthropods. They prey upon mites, aphids, psyllids, scales, woolly aphids, thrips, bark beetles, and the eggs of some Lepidoptera (Lattin 2000). The genus *Orius* is an important predator feeding on various insect pests as well as mites. From India, several anthocorid species have been identified as potential bioagents to target serious pests, for example, *Orius maxidentex* and *O. tantillus* on *Helicoverpa armigera*; *Cardiastethus exiguus*, *C. affinis*, and *Alofasodalis* on *Opisinia arenosella*; *Blaptostethus pallescens* on *Chilo partellus* and *Tetranychus urticae*; *Anthocoris muraleedharani* on *Ferrisia virgata*; *Montandoniola indica* on

Gynaikothrips uzeli and *Xylocoris* spp. on several stored grain pests (Ballal and Yamada 2016). Laboratory studies exhibited the potential of an anthocorid bug, *Amphiareus constric*tus (Stål) as a predator of tomato pinworm *Tuta absoluta* (Ballal et al. 2019).

Asopinae: The only subfamily of Pentatomidae which comprises predators. They feed on a variety of insects, especially the larval stages of insects belonging to Coleoptera, Lepidoptera, Hymenoptera, and other small and soft-bodied arthropods (Lefroy and Howlett 1909). However, they also feed on other insect orders or developmental stages. Around 30 species of Asopinae belonging to 17 genera are recorded from India (Salini 2019). *Eocanthecona furcellata* (Wolff), *Amyotea malabarica* (Fabricius), *Andrallus spinidens* (Fabricius), and *Zicrona caerulea* (Linnaeus) are the major predators of this subfamily. *Zicrona caerulea* feed on both adults and grubs of Chrysomelid beetles and *E. concinna* was found to be an efficient predator of various Lepidopteran insect pests affecting tea plantations (Srikumar et al. 2018).

Geocoridae: Geocorinae is the major subfamily that comprises predatory species. The genus *Geocoris* Fallén with its 147 valid species is the largest and most diverse taxon. Representatives of this genus are distributed in most of the biogeographic regions with warm and moderate climates (Kobór 2018). *Geocoris* comprises 33 species from India (Varshney and Ballal 2017). Several species of *Geocoris* are abundant and widely distributed. They prey upon thrips, mites, and aphids. For example, *G. ochropterus* Fieber is a predator on thrips (*Caliothripsindicus*, *Ayyariachaetophora*, and *Scirtothrips dorsalis*) which infest peanuts (*Arachis hypogaea*) (Kumar and Ananthakrishnan 1984).

Miridae: Mirids are one of the most abundant predators in horticultural crops such as tomato, eggplants, squash, and pepper (Sánchez et al. 2003). This is the largest and most diverse family of Heteroptera with more than 10,000 described species from the world (Schuh and Slater 1995). They predate on various insect pests such as spider mites, aphids, leafhoppers, and psyllids. Though the majority of them are pests of economic importance, a great many taxa, such as species of *Deraeocoris* Kirschbaum (Deraocorinae), *Hyaliodes* Reuter (Deraeocorinae), *Hyalochloria* Reuter (Orthotylinae), *Stethoconus* Flor (Deraeocorinae), and *Tytthus* Reuter (Phylinae), are effective predators (Henry 2000). A few species are commercially available in some countries and used to manage whiteflies. In India, *Dortus primarius* Distant was observed to be a potential predator of thrips (Varshney et al. 2018).

Reduviidae: The largest predaceous family of Heteroptera with total of 464 species belonging to 144 genera of Reduviids are reported from India (Ambrose 2006). They abundantly occur worldwide and feed on a variety of arthropods. *Rhyncocoris fuscipes* (Fabricius), *R. kumarii* Ambrose and Livingstone, *R. longifrons* (Stål) and *R. marginatus* Fabricius, *Ectomocoris tibialis* (Distant), and *A. pedestris* (Stål) have been successfully evaluated against a wider array of insect pests of cotton, vegetables, castor, groundnut, and cereals in India (Ambrose and Kumar 2016).

Carabidae: Bombardier beetles belonging to Brachininae comprising of 65 species from India, recorded as natural biological control agents of several agricultural pests like grubs of Rhinoceros beetles, larvae of mole crickets, aphids, etc. *Pheropsophus sobrinus* (Dejean) is one of the biocontrol agents used successfully to control Rhinoceros beetle larvae (Akhil and Sabu 2018). *Anthia sexguttata* Fabricius is another important predator of *Pyrausta machaeralis* Walker and *Hyblaea puera* Cramer in Tamil Nadu (CABI 2020).

Coccinellidae: About 550 species belonging to 90 genera of coccinellids are known from the Indian subcontinent. Genera such as *Macrolasia*, *Stictobura*, and most species of *Jauravia* are endemic to India (Poorani 2019). Coccinellids are predacious on aphids, psyllids, whiteflies, leaf- and planthoppers, scales, mealybugs, and early instar larvae of moths and butterflies, flies, beetles, bees, thrips, and mites. At present this family comprises 550 species under 90 genera in India. Under Chilocorini, members of the genera *Brumoides*, *Exochomus*, and *Priscibrumus* feed on mealybugs, scales, and aphids. The tribe Sticholotidini includes mainly scale feeders. The tribe Serangiini comprises specific predators of whiteflies and, to a lesser extent, scales. Species of the tribe Scymnini feed on aphids, mealybugs, scales, and whiteflies. Species of *Scymnus* are primarily aphid feeders (Poorani 2019). *Cheilomenes sexmaculata* (Fabricius) feeds on aphids, psyllids, whiteflies, mealybugs, tingids, leaf- and planthoppers, mites, and early instar lepidopteran larvae (Poorani et al. 2020).

Neuroptera: Among neuropterans, Chrysopidae is one of the major families of predatory insects, with 1415 species belonging to 81 genera reported from the world (Oswald and Machado 2018). Chrysopids or lacewings in their larval stage are important predators of aphids and scale insects. While adults of most chrysopid genera feed on nectar and pollen, in a few genera adults are predaceous. The common green lacewing, *Chrysoperla zastrowi sillemi* (Esben-Peterson), is a promising biological control agent of aphids and whiteflies (Nair et al. 2020). The larvae and adults of Coniopterygidae feed upon coccids, aphids, psyllids, mites, etc. They are important biocontrol agents of whiteflies and citrus mites. Five hundred seventy-one species belonging to 23 genera of Coniopterygidae are reported from the world (Oswald and Machado 2018). The Hemerobiidae, brown lacewings, are another predaceous group with 591 species in 28 genera reported from the world. The larvae and adults are primarily associated with trees and shrubs and less commonly with herbaceous plants. The Mantispidae, mantisflies (395 species in 44 genera from the world), is predatory on a large variety of Arthropods, the larvae are predatory on immature stages of beetles, flies, bees moths, and butterflies (Oswald and Machado 2018).

Thripidae: All species of *Scolothrips* are obligate predators of mites. All species of the genus *Leptothrips* of Phlaeothripidae are assumed to be predators and two species of *Karnyothrips* are predatory on-scale insects (Mound 2005). Varatharajan et al. (2018) studied the fauna of predatory thrips from northeast India and reported that the aeolothripids are represented by six species in five genera, thripids by a genus and a species, and the phlaeothripids by five species in three genera. They feed on various phytophagous species of thrips occurring on host plants like tea, turmeric, Schefflera, cashew, avocado, ficus, and several field crops (Varatharajan et al. 2018). Thrips are minute insects, comprising 6288 extant species in 782 genera (Thripswiki 2020). Though the use of predatory thrips in biological control programmes in India is limited, several predatory thrips were successfully used for the control of important pests in other countries. For example, Avocado thrips (*Scirtothrips perseae* Nakahara) was successfully managed by releases of *Franklinothrips orizabensis* Johansen in California Avocado orchards (Hoddle et al. 2004).

Entomophagous Lepidoptera: They are specialized to feed on Homoptera, chiefly on the sessile, colonial, and soft-bodied families of the Sternorrhyncha (which includes psyllids, aphids, scale insects, and mealybugs). *Spalgis epeus* (Westwood) is the most common predator of mealybugs such as *Coccidohystrix insolita* (Green), *Rastrococcus iceryoides* (Green), *Planococcus lilacinus* (Cockerell), and *Planococcus citri* (Risso), and aphids in India. *Dipha aphidivora* (Meyrick) is another promising biological control agent, which predates on bamboo aphids (*Pseudoregma bambusicola* and *P. alexanderi*) and sugarcane woolly aphid, *Ceratovacuna lanigera* Zehntner. It was recorded as an effective biological control agent of sugarcane woolly aphid in field conditions (Ghorpade et al. 2007, Poorani et al. 2020) (Plate 12.2).

12.6 Diversity of Pollinators

Pollination is an ecosystem process that has evolved over millions of years to benefit both flowering plants and pollinators. Pollinators visit flowers for many reasons, including feeding, pollen collection, and gaining warmth. When pollinators visit flowers, pollen rubs or drops onto their bodies. The pollen is then transferred to another flower or a different part of the same flower as the pollinator moves from one location to the next. This process is a vital stage in the life cycle of all flowering plants and is necessary to start seed and fruit production in flowers. Not only do pollinators provide essential services in nature, they are also necessary for healthy, productive agricultural ecosystems as they ensure the production of full-bodied fruit and fertile seed sets in many crops.

Although some plant species rely on wind or water to transfer pollen from one flower to the next, the vast majority (almost 90%) of all plant species need the help of animals for this task. There are approximately 200,000 different species of animals around the world that act as pollinators. Of these, about 1000 are vertebrates, such as birds, bats, and small mammals, and the rest are invertebrates, including insects like bees, flies, beetles, butterflies, and moths.

12.6.1 Contribution of Bee Pollinators to Agriculture

Animals pollinate approximately 75% of the crop plants grown worldwide for food, fibre, beverages, condiments, spices, and medicines. It has been reported that one out of every three to four mouthfuls of food human beings eat is delivered to them by pollinators. As such, agricultural products that are produced with the help of pollinators make a significant contribution to the economy. Worldwide, pollination services, including both those provided by managed honey bees domesticated in crop fields and those freely provided by wild non-apis bees, are valued at $219 billion per year contributing to 9.5% of global crop value (Calderone 2013). In California, one of the world's largest agricultural economies, wild non-apis bees alone provide pollination services valued between $937 million and $2.4 billion per year (Potts et al. 2011). Securing these essential and valuable pollination services is vital to achieving food security. Thus, it is evident that native pollinators serve as reliable sources of pollination services to the crops.

Among the 90% of flowering crops which are cross-pollinated, 85% depend upon insects for pollination. The principal pollinators are bees. Approximately 66% of the world's cultivated crops such as cashew, squash, mango, cocoa, cranberries, and blueberries are pollinated by a variety of bees (both honeybees and non-apis bees), 19% by flies, 6.5% by bats, 5% by wasps and beetles and 3.5% by birds, butterflies, and moths. Of the hundred principal crops that account for the world's food supply, only 15% are pollinated by domestic bees (mostly honeybees and bumblebees) and at least 80% are pollinated by wild non-apis pollinators (mostly leafcutter bees, sweat bees, mason bees, flies and butterflies) (Free 1993). Native pollinators like moths, flies, wasps, beetles, ants, birds, and bats improve agricultural yield by 20%. In the United States, native insect pollination saves the US economy to the tune of nearly $3.1 billion annually in crop production. Native pollinators contribute to $40 billion worth of crops produced annually in US alone (Chaudhary et al. 2013).

12.6.2 Diversity of Bee Pollinators

Apidae is a well-distributed and well-studied family that includes honeybees, bumblebees, and carpenter bees. The family Apidae comprises of three major subfamilies, viz. Apinae, Xylocopinae, and Bombinae, with around 25 genera of bees (Pannure 2016). The solitary bees belong to the families Megachilidae (leafcutter bees), Halictidae (sweat bees), Colletidae (cellophane bees), and Melittidae (digger bees). The number of species recorded in Apidae, Megachilidae, Halictidae, Andrenidae, Colletidae, and Melittidae was 241, 237, 194, 31, 32, and 1, respectively (Ascher and Pickering 2010; Gupta 2010; Saini and Rathor 2012).

12.6.3 Challenges/Factors that Affect the Diversity of Bee Pollinators

Bees are key pollinators, and their widespread decline has raised considerable concerns regarding the sustainability of ecosystems and food production. Pollinator decline is a global crisis, and the factors which lead to the decline include colony collapse disorder (CCD), overuse of plant protection chemicals, large-scale monocropping, crop intensification, climate change, land-use changes, agricultural policies, and fungal diseases. Native wild bees are of paramount importance in affecting the pollination of major agricultural crops. Native bees have a typical ability to sonicate the flowers of crops with poricidal anthers and contribute to the increase in yield, fruit, and seed set in tomato, brinjal, and other crops. In India, there is a paucity of data to scientifically prove that there is a decline in the population of native honey bees.

Monoculture: Monoculture is one of the major reasons for the loss of diversity of bee pollinators in an agro-ecosystem. This practice decreases the floral resource availability, and prevents the floral choice of the visiting bees, directly impacting their abundance in the field. An agro-ecological approach to enhance the diversity of pollinators is needed for sustainable pollination and increased crop yield. Bees inhabiting an intensively cropped farmland would be exposed to a monotonous diet which might negatively impact their fitness parameters. This negative influence of type and range of flowers on individual bee health and colony fitness in multiple ways, in terms of both pollen quality and diversity influencing longevity, physiology, and resistance or tolerance to disease, was documented in honeybees.

Habitat fragmentation: Habitat fragmentation refers to the development of fragments in the habitat of an organism negatively impacting the ecosystem. This occurs due to urbanization, climate change, and natural calamities, all resulting in the loss of biodiversity and extinction of bee pollinators.

Overdependence on pesticides: Overdependence on pesticides in intensive cropping systems with a loss of natural pest suppression would ultimately reduce the pool of native pollinators. The negative effect of pesticides on bees has been observed to be compounded by the loss of their natural habitats and their increased vulnerability to pathogens. Even when the chemical pesticides do not directly kill the bees, they alter their physiology and behaviour through sub-lethal effects, ultimately impacting colony build-up and their populations.

12.6.4 Conservation of Pollinators

The extent of the decline in the native bee population due to the various factors has to be understood to devise constructive ecological interventions to protect the bees. To conserve the bees, the vital stress factors over the survival of native bees have to be established. The loss of bees can be due to a number of complex factors along with their interaction, which poses significant challenges to the in-situ/ex-situ conservation of native bees. Sound crop management tactics with a focus on sustaining wild bee pollination services depend upon the balance between insect pest management practices and the conservation of the services provided by native bee pollinators. A large assemblage of native flowering crops within agriculturally dominated landscapes could preserve the native bees by serving as a refuge providing nectar, pollen, and hiding sites during the application of plant protection chemicals.

Artificial nesting sites: Non-apis pollinators need undisturbed nesting sites and access to nectar and pollen when the crop is not in bloom. They also need water, and some materials such as mud or leaves for nest building. Identification of natural nesting sites of leaf-cutting bees and conserving them in situ is an efficient method of conservation. Creating some bare grounds, leaving them undisturbed with a surrounding blooming flora will aid in conserving the nesting sites of ground-nesting bees (Fig. 12.1b). Many farms have some of these resources already; increasing such resources should improve native bee abundance over time. Planting plants with pithy stems (e.g. Peacock flower *Caesalpinia pulcherrima*) in gardens and pruning them periodically will promote their growth as well as invite the small carpenter bees for nesting in the pithy stems (Amala and Shivalingaswamy 2019). Nesting shelters can be provided in the form of cardboard blocks with holes and hollow bamboo stems (Fig. 12.1a) (Amala and Shivalingaswamy 2018), which will attract the leafcutter bees to build their nests.

Planting appropriate vegetation: The easiest way to attract native pollinators is to provide gardens or meadows with a diversity of native wildflowers, trees, and shrubs. A variety of wildflowers and native grasses can provide native pollinators with food in the form of nectar, pollen, and/or larval host plants. Trees and dense

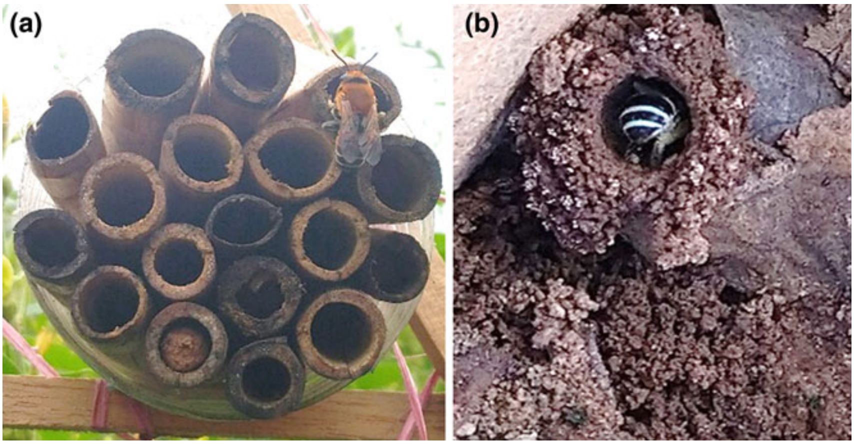


Fig. 12.1 (**a**) Leaf-cutter bee in an artificial trap. (**b**) Ground nesting bee, *Hoplonomia westwoodi*

shrubbery provide the required shelter, nesting site, and overwintering areas for pollinators. To maximize food and shelter, growers should include gardens, fruit-bearing trees and shrubs, thickets and hedgerows of flowering shrubs, and set-asides (areas that are not mowed) in their plans. Due to differing preferences among pollinator species, planted areas should contain varying levels of vegetation and areas of sun, partial shade, and full shade. Plantings should be done in locations that are sheltered from the wind.

Plants native to the region should be selected. Native plants are adapted to the local climate, soils, and the native pollinators with which they co-evolved. Native plants should comprise at least 75% of a habitat area. Invasive species should not be planted because they will degrade the pollinator and other wildlife habitats by interfering with the natural structure and composition of the ecosystem.

Mowed lawn areas should be minimized in favour of patches of native wildflowers, shrubs, and grasses. Existing lawn areas should be mowed less frequently to allow the vegetation to provide a natural habitat for pollinators. Perennials should be chosen over annuals. Perennials are generally richer in nectar and, because they bloom year after year, provide a more dependable food source than annuals. Each species of flower should be grown in a clump, as this will attract more pollinators than individual plants. Apart from these cropping systems, weeds (also called non-crop plants) in field margins support a large population of bees. Weeds help in maintaining the diversity of native bees by providing nectar and pollen source. The pollinators visiting the weed flowers can enhance the pollination and fruit set of crops adjacent to the field margins (Fig. 12.2a,b).

Judicious use of plant protection chemicals: Bees visit crop fields to feed, primarily when the crop is in bloom. Special care must be taken to protect these bees during the crop's bloom period. Avoiding insecticide applications immediately before, during, and directly after bloom and if sprays are required selecting only the most

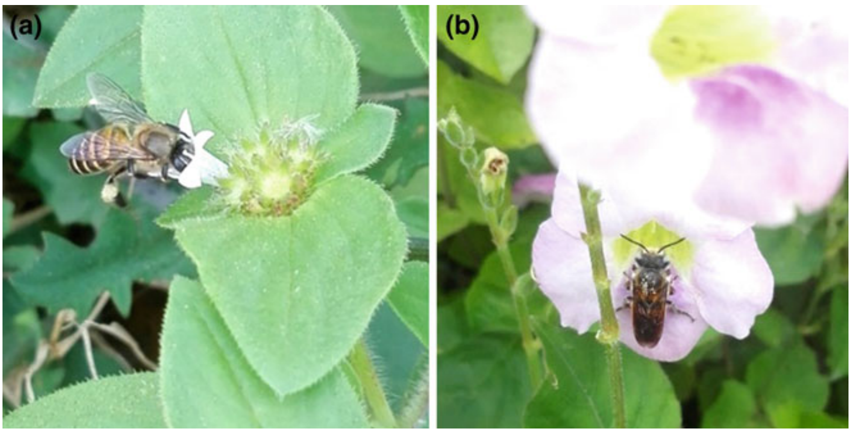


Fig. 12.2 (**a**) *Apis cerana* foraging on flowers of weeds, (**b**) Leafcutter bee, *Megachile* sp.

bee-safe products are the measures that support the enhancement of populations of non-apis pollinators. Selecting pesticides that are less toxic to bees should pay off over the long term by helping these native bees survive. Poisoning of pollinators may result from pesticide-contaminated food (pollen and nectar) or through direct contact with florets, leaves, soil, or other materials which have been exposed to pesticides. Insecticide use should be reduced, and herbicide use should be kept to a minimum to support the full range of native pollinators. The insecticide selected should be the least toxic to non-target insects like pollinators and used at the appropriate dosage and right time. Integrated pest management (IPM) measures involving safer components, viz. bioagents and biopesticides, use of pheromones, repellent compounds, and use of target-specific newer insecticidal molecules should be adopted, which can conserve pollinators.

To conserve and protect the pollinators, private seed companies can initiate a process of distribution of crop seeds along with seeds of biennial/perennial flowering plants as seed mixtures for sowing around the crop borders, which can attract and preserve the bee pollinators in agro-ecosystems. Installation of artificial trap nests in the agricultural fields is an innovative approach, which can attract native bees for nest construction and encourage their breeding.

12.7 Conservation of Natural Enemies

Biological control which focuses on either conserving or utilizing the diversity of natural enemies has emerged as one of the most effective, environmentally sound, and cost-effective pest management approaches as it is expected to drastically cut down the use of broad-spectrum pesticides and is considered to be a cornerstone of organic farming. In applied biological control, the challenge is to select an appropriate species or combination of species from a pool of natural enemies that will bring about the desired level of pest suppression with minimal impact on non-target species. The two strategies adopted are conservation and augmentation biological control. Conservation is the protection and restoration of species. Several anthropogenic activities and natural calamities are responsible for biodiversity loss. Thus, it is important to adopt conservation strategies either in situ or ex situ or both based on the requirement.

12.7.1 In Situ Conservation of Natural Enemies

Conservation of natural enemies is probably the most important, readily available, generally simple, and cost-effective strategy for pest management. Natural enemies occur in all production systems, from the backyard garden to the commercial field. They are adapted to the local environment and to the target pest, and their conservation is generally simple and cost-effective. With relatively little effort the activity of these natural enemies can be observed. For example, parasitized aphid mummies are almost always present in aphid colonies. These natural controls are important and need to be conserved and considered when making pest management decisions.

In many instances, the importance of natural enemies has not been adequately studied or does not become apparent until insecticide use is stopped or reduced. The best we can do is to recognize that these factors are present and see that there are no negative impacts on them. Natural enemies may be conserved by using insecticides or formulations which are least harmful and by timing applications to reduce the impact on beneficial arthropods. Ballal and Singh (2001) reported that non-intervention and thus conservation of natural enemies is the best strategy for *Helicoverpa armigera* management in the sunflower ecosystem. Studies have indicated that chemical inputs strongly affect beneficial insects and hence, compared to conventional farms, organic farms had a higher species richness and abundance of predators and parasitoids (Bengtsson et al. 2005). The Effect of insecticide inputs can go beyond the farm level. In the Midwestern United States, it was reported that crop pest abundance increased with the proportion of harvested cropland treated with insecticides (Meehan et al. 2011).

Besides biodiversity conservation, promoting biodiversity through local and landscape practices is extremely important. Thus, the focus should also be on the ecological management of farms through measures like increasing on-farm plant diversity and perennial plant cover. Conservation biological control practices such as refuges for natural bioagents, conserving weed plants harbouring predators and egg parasitoids, use of safer pesticides, judicious and selective use of non-persistent pesticides, strip treatment, and spot treatment were found to be effective conservation techniques in several crop ecosystems (Singh 2002). Local-scale intensification (e.g. fewer crop species and varieties, increases in chemical pesticide and fertilizers application, tillage, irrigation, and mechanization) can lead to the disturbance of biodiversity. Conservation tillage or no-till practices can lead to an increase in the populations of predators and parasitoids. However, some carabids and coccinellids prove to be exceptions. Diversity can be increased by planting non-crop vegetation like hedgerows which enhance natural enemy abundance (Nicholls and Altieri 2013). Use of kairomones, synomones, pheromones, adjuvants, etc. to increase the searching ability and retention of parasitoids; build-up of the population of biocontrol agents by providing artificial structures, food, alternate host, suppression of ants, etc. (eg. provision of grain sorghum in the cotton plot, which serves as a source for natural enemies) are also some conservation techniques. Though agricultural intensification is known to have a detrimental effect on biodiversity, the real mechanisms underlying the effect of biodiversity on biological control are not well understood. Crowder and Jabbour (2014) suggest experimental frontiers, viz. evenness, realistic manipulations of biodiversity, and functional and genetic diversity to understand the processes in real-world agroecosystems. Liere et al. (2017) state that agriculture management practices affect the performances of natural enemies by altering the resources base, species pool, and their interactions. It is important to study the cascading effects of landscape drivers on pest control by natural enemies.

Habitat manipulation techniques can be easily incorporated into home gardens and even small-scale commercial plantings but are more difficult to accommodate in large-scale crop production. There may also be some conflict with respect to pest control because of the difficulty in targeting the pest species as the refuges may be used by the pest insects as well as natural enemies. Habitat manipulation involves altering the cropping system to augment or enhance the effectiveness of a natural enemy. Many adult parasitoids benefit from sources of nectar and the protection provided by refuges such as hedgerows, cover crops, and weedy borders. Mixed plantings and the provision of flowering borders can increase the diversity of habitats and provide shelter and alternative food sources. For leaf- and planthoppers, colonization of mirid predator *Cyrtorhinus lividipennis* has proved to be effective. Weeds like *Cyperus* sp. help in the off-season survival of mirid bugs through harbouring planthoppers. Predation by mirid bug was more on brown planthopper (BPH) resistant rice variety PTB 33. It was reported that the presence of any combination of three nos./hill of spider *Lycosa preudoannulata*, *Oxyopus javanus*, and *Tetragnatha* sp. checked the population of BPH and White-backed planthopper (WBPH).

Natural enemy populations may be enhanced by increasing the diversity of plant species in the vicinity of the crop, changing cultural practices to ensure continuous availability of hosts, and providing alternative food sources (Pawar 1986). Landscape heterogeneity and complexity generally benefit natural enemies. Marino and Landis (1996) observed parasitism rates to be positively correlated with landscape complexity. Gardiner et al. (2009) reported higher predation rates of soybean aphids by coccinellids in soybean fields where landscape heterogeneity was maintained. Tylianakis et al. (2007) reported higher parasitism rates across the pasture, rice, and coffee systems where parasitoid diversity was higher. However, according to Schmitz (2007) in 40.3% of cases, predator diversity negatively influences predation, which could be due to interspecific inference or competition. Research taken up at research farms across the country and at farmers' fields in Telangana, which is a rice hopper-prone area, indicated that flowering forbs on rice bunds have a positive impact on predator biodiversity and improved parasitization of hopper eggs. Border plants increased parasitization of yellow stem borer egg masses (Chitra and Katti 2017).

Salliou and Barnaud (2017) reported that though scientific findings suggest that natural enemy habitats are conserved through maintaining complex landscapes, there were no steps taken upto convince the farmers of the importance of landscape as a resource for conservation biological control. Thus, networking between landscape ecologists and farmers is extremely important, through which growers can be encouraged to conserve biodiversity. Awareness could be created amongst farmers on ecological engineering, diversified crop rotations, coupling of crop and livestock production, etc.

12.7.1.1 Indigenous Parasitoids and Predators to Be Conserved

Indigenous Parasitoids

A successful parasitoid should have a high reproductive rate, good searching ability, host specificity, be adaptable to different environmental conditions, and be synchronized with its host (pest). No parasitoid has all these attributes, but those with several of the above characteristics will be more important for use in suppressing pest populations. In nature, several parasitoids have been observed to be potential bioagents of serious crop pests. The emphasis should be on documenting the important natural enemies which play a major role in pest suppression and conserving them. Here, we are citing a few examples. *Anagyrus dactylopii* was recorded as a dominant parasitoid parasitizing up to 90% of citrus mealybug *Nipaecoccus viridis* (Subba Rao et al. 1965). On cabbage, cauliflower, and other cole crops, diamondback moth (DBM), *Plutella xylostella*, is a major pest and *Cotesia vestalis* is an important parasitoid in the regions with tropical and sub-tropical climates (Nagakatti and Jayanth 1982), and *Diadegma semiclausum* in regions with temperate climate viz. the Nilgiris (Chandramohan 1994). *Campoletis chlorideae* and *Eriborus argenteopilosus* are important early larval parasitoids of *Helicoverpa armigera* in the pigeonpea and chickpea ecosystems (Bilapate et al. 1988). Strain variations were observed in *C. chlorideae* based on the geographical location, and the Sehore strain was observed to be the most efficient (Ballal and Ramani 1994). Variations were observed in the performance of *C. chlorideae* populations collected from different crop ecosystems. The lab-reared parasitoids which were originally from the pigeonpea ecosystem could not efficiently parasitize *H. armigera* larvae from the cotton ecosystem, whereas the parasitoids from the cotton ecosystem were capable of parasitizing more than 40% of the larvae of cotton ecosystem (Ballal et al. 2001). The studies clearly indicated that the performance of *C. chlorideae* is largely governed by the host plants on which the pest and parasitoid were originally recorded. Bajpai et al. (2002) reported that on chickpea plants, the chemical cues released during feeding by *H. armigera* were essential for *C. chlorideae* to be attracted to the infested plants and to induce parasitism. Parasitism was also governed by host plant variety (Ballal and Gupta 2003).

On citrus butterfly *Papilio demoleus* Linnaeus, egg parasitoid *Trichogramma chilonis* parasitized up to 76% and *Telenomus* sp. nr. *incommodus* 78% (Krishnamoorthy and Singh 1988; Jalali and Singh 1990). *Distatrix papilionis* is the dominant parasitoid of caterpillars and *T. chilonis*, *T. incommodus*, and *D. papilionis* caused cumulative parasitism of 88% (Krishnamoorthy and Singh 1988). *Trichogramma chilonis*, *Melalophacharops* sp., and *D. papilionis* could be utilized for the biological suppression of butterflies attacking citrus. The eggs of fruit sucking moth, *Othreis fullonia* are successfully parasitized by *T. chilonis*, which suggests the possibility of utilizing *T. chilonis* for the control of this pest (Dodia et al. 1986). Biodiversity and biocontrol researchers should focus on understanding the population dynamics of the important indigenous parasitoids and provide recommendations to farmers to refrain from indiscriminate use of chemical insecticides and adopt the right habitat manipulation strategies to conserve parasitoids.

When invasive pests enter our country, the general strategy is to import exotic biocontrol agents from the country of origin. A successful example is that of the importation of a parasitoid *Acerophagus papayae* to manage the papaya mealybug, which has now established throughout the country and formed a part of the Indian insect diversity. However, there are excellent examples of indigenous parasitoids working as efficient bioagents of invasive pests—the indigenous parasitoid *Encarsia flavoscutellum* which could manage the invasive sugarcane woolly aphid (SWA); *Encarsia guadeloupae* which could manage the invasive rugose spiraling whitefly and a complex of indigenous natural enemies which could manage the fall armyworm (FAW) (Shylesha et al. 2018).

Indigenous Predators

In India, several predators have been identified as potential biocontrol agents. For instance, more than 60 arthropod species have been recorded as predators of *Helicoverpa armigera* (Hübner). Chrysopids, anthocorids, ants, coccinellids, and spiders are the important predators reported feeding on *H. armigera* in India (Manjunath et al. 1989).

The important indigenous coccinellid predators include *Coccinella septempunctata* Linnaeus, *Scymnus coccivora* Ayyar, *Chilocorus nigrita* Fabricius, *Cheilomenes sexmaculata* (Fabricius), and *Brumoides suturalis* (Fabricius). Amongst syrphids, the important ones include *Ischiodon scutellaris* (Fabricius), *Paragus serratus* (Fabricius), and *Paragus yerburiensis* Stuckenberg. Aphidophagous coccinellid, *C. septempunctata*, is more abundant in areas with low average temperature, viz. northern parts of India. It plays an important role in the natural suppression of aphids like *Myzus persicae* (Sulzer), *Brevicoryne brassicae* (Linnaeus), and *Lipaphis erysimi* (Kaltenbach) infesting *rabi* oilseeds and cole crops. Similarly, syrphids like *I. scutellaris* and *Paragus* spp. are also found in large numbers feeding on these aphids. *Cheilomenes sexmaculata* is more abundant in warmer areas of southern India and keeps *Aphis craccivora* Koch, infesting groundnut and pulses under check during summer and *kharif* seasons. Amongst indigenous coccidophagous coccinellids, *C. nigrita* has been utilized through inundative release, not only against the sugarcane scale *Melanaspis glomerata* (Green) but also against several other diaspine scales including red scale of citrus (Singh 1994). Other important coccinellids in this group are *Pharoscymnus horni* (Weise) and *S. coccivora*. By virtue of their small size, they are able to enter leaf sheath and crevices of bark, where crawlers of coccids generally reside and feed on them at an early stage of crop infestation.

In India, several species of Chrysopids have been recorded from various crop ecosystems. Some species are distributed widely and are important natural enemies of aphids and other soft-bodied insects. Amongst them, *Chrysoperla zastrowi sillemi*, *Mallada boninensis*, *Apertochrysa crassinervis*, and *Mallada astur* are the most common. The first two were mass-reared and utilized in the cotton ecosystem for protection from aphids and other soft-bodied insects. *Chrysoperla zastrowi sillemi* has been recorded on cotton, green gram, sorghum, maize, safflower, sunflower, and pigeonpea, predating on several pests, viz. safflower aphid, maggots of safflower fruit fly, eggs of pentatomid bugs on green gram, sorghum aphid, eggs of Pyrilla, cotton aphid and leafhoppers. In Himachal Pradesh, *C. z. sillemi* feeds on apple woolly aphid *Eriosoma lanigerum* colonies and hibernates in cocoons as pre-pupae from the first week of November to early March. Lepidopteran predator *Dipha aphidivora* and chrysopid predator *Micromus igorotus* were recorded as naturally occurring bioagents of the invasive Sugarcane Woolly Aphid.

Amongst the different anthocorid predators recorded in other countries, *Orius* spp. appear to be the most promising, especially against thrips; examples being *Orius sauteri*, *Orius majusculus*, *Orius laevigatus*, and *Orius insidiosus*, and these predators are being commercially produced and sold for pest management. In India, anthocorids have been recorded as naturally occurring promising bioagents of different species of thrips in various ecosystems. *Orius tantillus* and *O. maxidentex* are the most common species recorded. Understanding the seasonal abundance of these predators is important to arrive at conservation strategies to be adopted at the right time and stage of the crop.

12.7.2 Ex Situ Conservation of Natural Enemies

Ex situ conservation is the conservation of species or components of biodiversity outside their natural habitat to protect them from all the abiotic and biotic adverse effects. In ex situ conservation of natural enemies, predators and parasitoids are multiplied in repositories/insectaries under the supervision of experts by providing the required food and facilities. When the natural enemy populations in the field situations are not adequate to manage the pest, the ex situ-conserved natural enemies are released into the field under augmentative biological control programmes. Ex situ conservation is also important for conducting laboratory and field validation trials prior to field releases. Some of the parasitoids and predators have become so important in augmentation biocontrol programmes that maintenance of these well-characterized species is extremely useful and valuable. Commercialization of macrobials is exempt from registration requirements, hence can be commercially produced and sold by even small start-ups. Hence, to support augmentation biological control programmes, it is crucial to maintain a global ex situ resource base with sharing of knowledge and technology and provision for exchange of these valuable resources for global biocontrol programmes. Development of standard production protocols and setting up of insectaries for multiplication of beneficial insects are the preliminary steps in ex situ conservation of natural enemies.

Van Lenteren (2012) reported that the history of commercial mass production and sale of natural enemies spans a period of roughly 120 years. Everett J. Dietrick started the first insectary in his garage in Riverside, California, in 1950 (Dietrick 1981). Worldwide 170 species of arthropod natural enemies are produced and sold for biological control of more than 100 pest species (Cock et al. 2010). To augment natural enemies, insectaries are required for the continuous production of these agents. Several countries have commercial insectaries where biocontrol agents (BCAs) are produced round the year.

Worldwide, there are 530 commercial insectaries. Among them, around 30 are large producers, of which 20 are located in Europe (Bolckmans 2008) and about 500 are small commercial producers. Most of the commercial insectaries primarily rear predators and parasitoids, with a few producing entomopathogenic nematodes.

During 1972–2002, a number of commercial insectaries were set up in Latin America to initiate augmentative biocontrol. Colombia had 30 insectaries for mass multiplication of natural enemies in 1990 which decreased to nine during 2000, which is a matter of concern. In Mexico parasitoids, predators, and pathogens are mass-produced in more than 30 units. Peru has 82 mass-rearing facilities for natural enemies and 27 laboratories for the production of entomopathogens (Beingolea 1996; van Lenteren and Bueno, 2003) in which a total of 27 species of biocontrol agents are mass-produced.

In India, ICAR-National Bureau of Agricultural Insect Resources, Bengaluru, holds the largest insect repository with more than 130 live insect cultures being maintained round the year. Among 130 live insects, 108 are parasitoids (including different species and strains). Each year, around 1500 shipments containing 43 million live insects are dispatched to various universities, research organizations, commercial units, and farmers across India. Through this effort, potential natural enemies get re-introduced into the field, which restores biodiversity besides facilitating pest management. Central IPM centres in different parts of the country and State Biocontrol labs have the mandate to conserve bioagents in situ and ex situ. The Biocontrol Research Laboratories (under Pest Control India Ltd.) was the first commercial biocontrol unit in India. Today, there are a few commercial insectaries in our country, and some farmers have also taken up the production of biocontrol agents. However, the interest to take up the production of microbial biopesticides is more in comparison to that for macrobials.

The setting up of more insectaries would provide a backup and an additional measure to complement in situ conservation strategies. Broadly, ex situ conservation of natural enemies play an important role in managing genetic resources, educating all stakeholders, supporting research initiatives, and collaborating with in situ conservation efforts (Kasso and Balakrishnan 2013).

12.7.3 Challenges Faced in Conserving the Diversity of Natural Enemies

Pesticides: The insecticides used in agroecosystems to manage insect pests pose several threats to the ecosystem, viz. insecticide resistance, environment contamination, secondary pest outbreaks, and death of non-target organisms, including the natural enemies, which are naturally present in the ecosystem. Insecticides can come in direct contact with natural enemies or through the host, or through the insecticide-treated pollen, nectar, and other plant parts. Gusmão et al. (2000) observed the toxicity of organophosphates to predatory wasps *Apoica pallens* (Fabricius) and *Brachygastra lecheguana* (Latreille) of *Leucoptera coffeella* (Guérin-Mèneville & Perrottet). Cabral et al. (2008) reported the reduction in survival of larvae of the ladybird beetle *Coccinella undecimpunctata* by 33% when exposed to the recommended dose of the insecticide buprofezin. Bacci et al. (2007) studied that organophosphates and neonicotinoids caused more than 61% mortality of the parasitoid *Encarsia* sp. Similarly, fenitrothion and deltamethrin reduced the adult emergence of *Trissolcus grandis* Thompson by 18.0 and 34.4%, respectively, when used to manage *Eurygaster integriceps* (Puton) (Saber et al. 2005). Suh et al. (2000) reported that some of the chemical insecticides adversely affected *Trichogramma* emergence from *Helicoverpa zea* (Boddie) eggs when exposed at different pre-imaginal stages of development.

Insecticides also affect the growth and development of predators and parasitoids, which in turn disrupts their phenological synchrony with the susceptibility of the insect host. Insecticides also affect the sex ratio, fecundity, fertility, and longevity of insects (Figa-Talamanca et al. 2001; Fernandes et al. 2008). Gradually it leads to the loss of the species from that particular habitat. Carvalho et al. (2003) studied a negative effect on adult viability and fertility of eggs of *Chrysoperla externa* when immature stages of this predator were exposed to the insecticide tebufenozide. The emergence of adults of the endoparasitoid *Hyposoter didymator* was affected by exposure to Spinosad (Schneider et al. 2004). Mäder et al. (2002) observed high numbers of spiders and carabid or staphylinid beetles in organic plots than in conventional plots. In alfalfa, the diversity of spiders was affected when imidacloprid was used (Liu et al. 2008).

Urbanization: Demographic and economic growth leads to modification in natural and semi-natural habitats, thus causing loss of biodiversity. Urbanization leads to habitat fragmentation which can influence the searching ability of natural enemies to locate the prey/host and other plant resources for nectar and pollen. It also reduces the resources for the prey and thus affecting the diversity and abundance of predators and parasitoids (Corcos et al. 2019).

Agriculture intensification: Agricultural intensification, through increased fertilization input within fields and cropland expansion at landscape scales, can also disturb the natural habitats and lead to loss of biodiversity (Zhao et al. 2013). At the field scale, an increase in nitrogenous fertilizers changes plant nutrition which might be beneficial for the phytophagous pests, while they are detrimental to natural enemies (Awmack and Leather 2002). Zhao et al. (2015) studied the relative importance of nitrogen input and cropland expansion on cereal aphids and their natural enemies, and they found that this intensification benefited cereal aphids more than primary parasitoids and leaf-dwelling predators, leading to disturbance of the interspecific relationships. More intensive agriculture frequently reduces the availability of non-crop habitats which could be a source of alternate hosts for the natural enemies (Langer and Hance 2004).

Introduction of non-native/alien species and biodiversity loss: Invasive species are a great threat to native biodiversity. In the absence of natural enemies, the invasives breed and spread at a rapid pace, completely taking over the area of invasion. Invasive species can alter the food web in an ecosystem by destroying or replacing native food sources and thus altering the abundance and diversity of species. There are a few instances wherein a few natural enemies which were introduced into some countries under classical biological control programmes to manage invasives subsequently became not only a pest but also a threat to native biodiversity. Hence, potential negative or non-target effects of introduced agents should be considered before importing them, more so before releasing them into the field situations. The harlequin ladybird (or multicoloured Asian lady beetle), *Harmonia axyridis* (Pallas), a native to Asia was widely introduced as a biological control agent of pest aphids and has spread to many countries (Brown et al. 2008). The global invasion of *H. axyridis* has been rapid (Brown et al. 2011). A number of large-scale analyses have indicated the adverse effect of this predator on the declines of native species in the USA (Losey et al. 2014) and Europe (Roy et al. 2012). Realizing that generalist predators and parasitoids with multiple generations in a year and multiple hosts may affect non-target organisms, the utmost care has to be taken prior to field releases.

Farmers' attitude: Farmers are familiar with the use of chemical insecticides and can be easily convinced on chemical pesticide applications based on their availability and the visible and quick knockdown effects. Since the initial impact of biological control is not visible and since bioagents are generally slow in their actions, it is hard to convince and change the mindset of farmers. Therefore, it is important to educate them on the long-term benefits of biocontrol on the environment, biodiversity, and animal and human health. They should also be trained on distinguishing a biocontrol agent from a pest. Some progressive farmers are well aware of the benefits of biological control, but regional availability of biocontrol agents is a hurdle. To overcome the negative attitude of farmers towards conservation of natural enemies or adoption of integrated pest management (IPM) practices, networking of farmers/growers and extension functionaries/KVKs with research organizations is very important. Through farmer participatory trials, they can be exposed to the benefits and risks in IPM practices compared to conventional practices (Barratt et al. 2018) (Figs. 12.3 and 12.4).

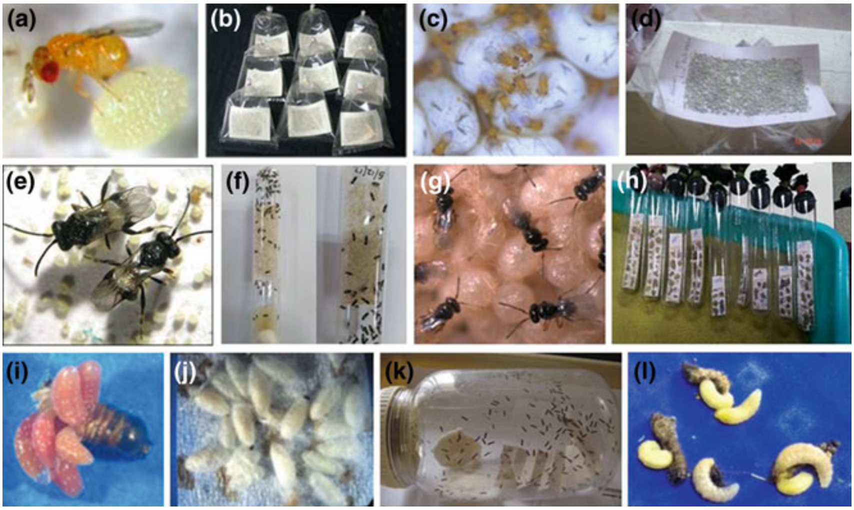


Fig. 12.3 Ex situ conservation of important parasitoids at the Live Insect Repository, ICAR-NBAIR, Bengaluru. (**a**)–(**d**) Egg parasitoid *Trichogramma* spp. and Trichocards on *Corcyra cephalonica* (Stainton) eggs and eri silkworm eggs; (**e**) and (**f**) Egg larval parasitoid *Chelonus blackburni* (Cameron) parasitising *C. cephalonica* eggs and its production; (**g**) and (**h**) Egg parasitoid *Telenomus remus* Nixon parasitising *Spodoptera litura* eggs and its production; (**i**)–(**k**): Larval parasitoid *Goniozus nephantidis* (Muesebeck) and its production; (**l**) *Chelonus formosanus* Sonan

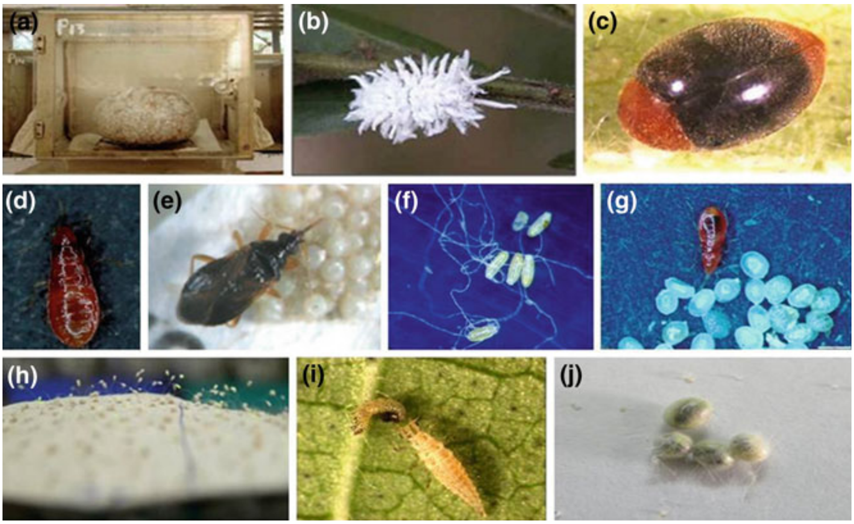


Fig. 12.4 Ex situ conservation of important predators at the Live Insect Repository, ICAR-NBAIR, Bengaluru. (**a**)–(**c**) *Cryptolaemus montrouzieri* Mulsant - production, grub and adult stages; (**d**) and (**e**) *Blaptostethus pallescens* Poppius - Nymph and adult; (**f**) and (**g**) *Cardiastethus exiguus* Poppius; - eggs and nymph (**h**)–(**j**) *Chrysoperla zastrowi sillemi* (Esben-Peterson) - eggs, grub and cocoons

12.8 Documentation and Conservation Efforts by the Central and State Governments

Considering the importance of identification, documentation, conservation, and utilization of insect resources, several organizations have been created, projects formulated, and existing organizations with the above mandate have been strengthened. Insect museums have been set up under various state agricultural universities and ICAR institutes. Maharana Pratap University of Agriculture and Technology, Udaipur; Indian Agricultural Research Institute, New Delhi; Tamil Nadu Agricultural University, Coimbatore; University of Agricultural Sciences, Bangalore; ICAR-NBAIR, Bangalore; Forest Research Institute, Dehradun; Zoological Survey of India, Calcutta; and Aligarh Muslim University, Aligarh, are some of the organizations which have state-of-the-art insect museums focusing on the collection, identification, and preservation of insect specimens and thus focusing on documentation of the Indian insect diversity.

The ICAR-NBAIR, Bangalore, which is also the nodal centre for the All India Coordinated Research Project on Biological Control with the 28 centres under AICRP Biocontrol has the mandate to conserve and utilize insect resources. Awareness of the importance of non-chemical modes of pest management is created amongst farmers through demonstration trials, farmer participatory trials, and on-farm trials in different parts of the country. ICAR-NBAIR also conducts in-depth research on pest management through the utilization of bio-pesticides and semiochemicals, thus reducing chemical pesticide pressure and conserving the beneficial insects, viz. parasitoids, predators, and pollinators, and augmenting the population of pollinators through the creation of artificial nesting sites. NBAIR with its largest Live Insect Repository conducts training programmes for researchers, students, department officials, commercial entrepreneurs, and farmers on production, conservation, and utilization of insect resources. The All-India Network project on Honeybees and Pollinators with its centres in different parts of the country focuses on documenting and conserving the different species of honeybees and other pollinators. Sufficient funds to take up research on insect diversity are provided by ICAR, DST, DBT and other funding organisations.

12.9 Future Thrusts

- Though clear evidence is lacking, it is strongly felt that climate change may alter the populations of pests and natural enemies and thus the effectiveness of biological control. Hence, it is very important to take up studies on the short- and long-term effects of climate change on harmful and beneficial insects. Modelling studies and consolidation of all existing studies done in various parts of the country, incorporating the vast resources of data from various government agencies, are of prime importance. Climatic pattern mapping and climate mapping of a region are important in terms of risk assessment of pests as well as for biocontrol introductions. Eco-climatic assessment can provide valuable insight into species distribution, in relation to relevant climate data, particularly relating to the assessment of the potential establishment of a particular biocontrol species.

- A long-term funded research project in specific regions to understand if there is any loss in insect diversity and identification of the factors leading to the loss.
- Initiation of studies on the methodology to quantify insect diversity through identification of indicator species and provide inputs towards developing an agrobiodiversity index.
- Network project on insect taxonomy to be set up on priority, with international training and collaboration avenues for Indian taxonomists for bilateral exchange of specimens. Networking between Indian Insect Museums with provisions for exchange of specimens.
- Incentives for entrepreneurs to set up commercial insectaries.
- Automation in production and long-term storage strategies to be developed for the important beneficial insects.
- Indian biocontrol workers to be trained on advanced production and release techniques adopted by commercial insectaries abroad.
- Standard production procedures to be developed and followed by all insectaries. Strict quality control protocols to be followed by all insectaries. Uniform release and evaluation techniques to be followed by all biological control researchers, which would enable the comparison of results.
- Population dynamics of the pest and the natural biological control agents to be studied in detail before introducing an exotic natural enemy.
- In-depth studies on tri-trophic interactions between the pest, parasitoid, and host plant.
- Large-scale field trials to evaluate the effectiveness of natural enemies in different agro-climatic regions.
- Systematic studies on the role played by indigenous natural enemies and pollinators in crop protection and crop yield.
- Studies on kairomonal interventions to improve the performance of parasitoids and predators.
- Development of superior strains of parasitoids and predators: viz. insecticide tolerant, high temperature tolerant, and high searching ability.
- Future biocontrol attempts must consider climate variables in evaluating long-term effectiveness.
- Provision for bilateral exchange of biocontrol agents for tackling invasive pest attacks and thus aiming at global biocontrol initiatives and successes.

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Chapter 13
Biodiversity Issues and Challenges: Non-agricultural Insects

Kailash Chandra and Devanshu Gupta

13.1 Introduction

With more than one million named species (10,78,506), insects are the most diverse terrestrial creatures on the planet, representing around 75% of the global fauna (Table 13.1; Fig. 13.1) with more than 80% yet to be described (Zhang 2011, 2013a, b; Adler and Foottit 2017). Stork (2018) assessed more than 5.5 million insect species on our planet. This remarkable richness and diversity of insects on land is the outcome of their evolutionary success. They became abundant in the Middle Silurian to Early Devonian period (420 to 405 million years ago) and by the Late Carboniferous (323 to 299 million years ago) (Labandeira 2018). They are the significant components of both terrestrial and aquatic ecosystems from the equator to the arctic region and from sea level to the snowfields of the highest mountains, on land, in air, and in water—almost everywhere. Insects contribute invaluable ecosystem functions such as nutrient cycle, pollination, and seed dispersals. They serve as a significant food source for other organisms, help in the biocontrol of other organisms (such as predators, parasites), and maintain soil structure and fertility. Meantime, they are profoundly beneficial as pollinators. They often come into direct competition with humans, as pests of agriculture and stored products and as vectors of life-threatening diseases.

In modern classification, the classes, Insecta, Collembola, Protura, and Diplura form subphylum Hexapoda in phylum Arthropoda (Zhang 2013a, b). The first entomologist who made extensive studies of Indian insects was Fabricius (1775, 1782, 1787, 1793, 1798, 1804), and the publication of Carl Linnaeus (1758) provided the earliest record of Indian insects, with descriptions of 28 species. Later, different workers carried out the compilation of India's data on insect fauna from time to time. Maxwell-Lefroy and Howlett (1909) included 25,700 species of

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Table 13.1 Insect diversity (Arthropoda: Hexapoda) of the world and India

Classes	Orders	Number of species		
		World	India	Percentage of world
Collembola		9000	345	3.83
Protura		816	20	2.5
Diplura		976	18	1.84
Insecta		1,067,902	66,728	6.2
	1. Archaeognatha	513	11	2.14
	2. Zygentoma	564	29	5.14
	3. Ephemeroptera	3700	152	4.1
	4. Odonata	6312	496	7.9
	5. Orthoptera	28,650	1166	4.06
	6. Phasmida	3350	140	4.2
	7. Embioptera	457	32	7.0
	8. Plecoptera	3700	146	3.94
	9. Dermaptera	2375	293	12.3
	10. Mantodea	2519	184	7.3
	11a. Blattodea (cockroaches)	4837	181	3.74
	11b. Blattodea (termites)	2942	295	6.63
	12. Psocoptera	5611	126	2.24
	13. Phthiraptera	5316	466	8.8
	14. Thysanoptera	6288	754	12.0
	15. Hemiptera	107,180	6479	6.04
	16. Hymenoptera	154,067	10,605	6.9
	17. Strepsiptera	627	28	4.5
	18. Coleoptera	386,755	22,334	5.8
	19. Neuroptera	5917	327	5.5
	20. Megaloptera	386	30	7.8
	21. Raphidioptera	253	5	2.0
	22. Trichoptera	16,267	1299	7.6
	23. Lepidoptera	158,423	13,694	8.6
	24. Diptera	157,971	7382	4.6
	25. Siphonoptera	2185	51	2.3
	26. Mecoptera	737	23	3.1
	Total (Collembola+Protura +Diplura+Insecta)	1,078,506	67,111	6.2

insects from India and adjacent countries in their famous book *Indian Insect Life*. Beeson (1941) and Menon (1965) estimated the number of species from India to be 40,000 and 50,000, respectively.

Varshney (1997) reported 51,450 species under 589 families. Subsequently, Varshney (1998) reported the occurrence of 59,353 species belonging to 619 families in India. Recently Chandra (2011) analyzed the insect fauna of states and union territories of India and reported 63,760 species under 658 families. In this chapter, an

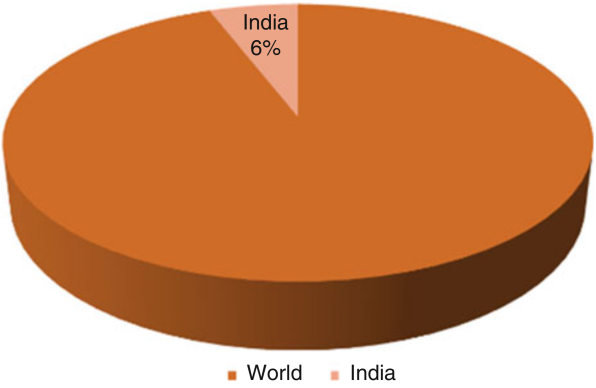

Fig. 13.1 Insect diversity across the globe and India

attempt has been made to review and update the known insect diversity of India with emphasis on their diversity in the freshwater ecosystem, mangroves, soil, and forests. Additionally, the diversity of insects in the Himalayas, Trans-Himalaya, deserts, and islands is concisely presented along with edible insects, invasive alien insect species, and insects of medical and veterinary significance. A list of threatened insects is also provided with the major threats faced by insect populations in the country.

13.1.1 Insect (Arthropoda: Hexapoda) Diversity of India

Owning four of the globally recognized biodiversity hotspots—Himalaya, Indo Burma, Western Ghats and Sri Lanka, and Sundaland—India is represented by 103,445 faunal species of different terrestrial and marine phyla (Chandra et al. 2019d), of which phylum Arthropoda alone holds over 77,560 species (74.8%) (Fig. 13.2). 64.8% of the overall faunal diversity of the country (67,111 species) exclusively includes insects (Fig. 13.2), represented by four classes of subphylum Hexapoda: Collembola (345 species), Protura (20 species), Diplura (18 species), and Insecta (66,728 species) (Table 13.1). Eight insect orders—Coleoptera, Lepidoptera, Hymenoptera, Diptera, Hemiptera, Orthoptera, Thysanoptera, and Odonata—form the majority (94%) of the insects in the country. In contrast, the remaining 6% of species constitute 18 small orders. The order Coleoptera has the highest diversity at the family level (114) followed by Hemiptera (92), Diptera (87), Lepidoptera (84), and Hymenoptera (65).

Only 4.7% (3130 species) of insect diversity of the country depend on agroecosystems (Chandra et al. 2020b) (Table 13.2). Insects in the agroecosystem play a vital role in crop production as pests of crops, predators of other insects, and parasitoids. The majority of the insects (63,981 species), directly and indirectly, occupy the forest ecosystem. Except for the few pest species, little is known about the bionomics, host association, and habitat of a significant proportion of species.

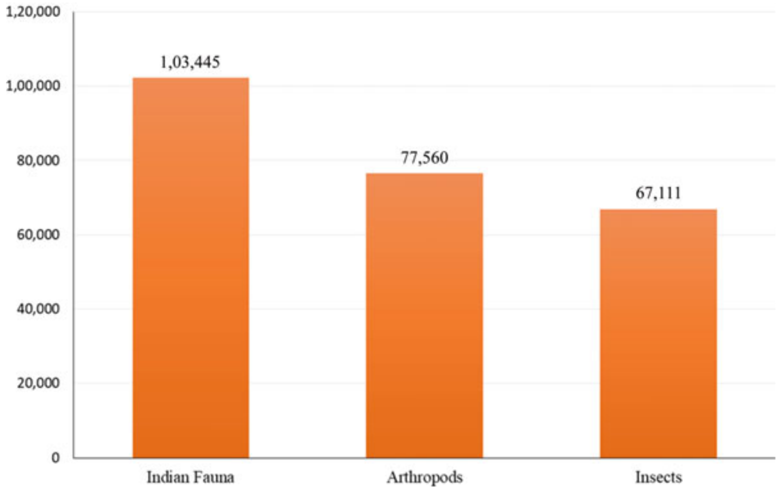

Fig. 13.2 Comparison of overall faunal diversity of India with arthropods and insects

Table 13.2 Known species richness of total fauna and insects in different ecosystems and biogeographic zone of India

Ecosystem/biogeographic zone	Number of species		Percentage against overall fauna of ecosystem/ biogeographic zone	Percentage against insect fauna of India
	Fauna	Insects		
Agroecosystem	5820	3130	53.6	4.7
Freshwater	9456	5014	52.6	7.4
Soil (Belowground)	22,586	13,711	60.7	20.5
Mangroves	4822	1461	30.3	2.9
Himalaya	30,615	25,064	81.9	37.5
Trans-Himalaya (Cold Desert)	3324	2291	68.9	3.4
Desert (Thar)	3346	1580	46.7	2.3
Island	11,009	3572	32.4	5.3

The Himalayan ecosystems are comparatively diverse than other geographical regions, including 37.5% of the overall insect diversity (Table 13.2).

Though the insect diversity of India is comparatively rich and well known, revisionary works on smaller and lesser-known groups are required. There is also a need to write the Fauna of India on various families of the economically essential groups, as the Fauna of British India volumes are comparatively old and outdated. It is also necessary to undertake studies on DNA barcoding, especially pests and biological control agents, to solve the problems of identification in species complexes. Despite their ecological importance, the conservation of insects in India has not yet received much attention. Therefore, it is required to investigate the effect of climate change and habitat fragmentation on the diversity and distribution of insects.

13.1.2 Class Collembola

Collembolans are small-sized, wingless, and entognathous insects, predominately found in soil and litter (Gullan and Cranston 2014). Nine thousand species represent global diversity (Bellinger et al. 1996–2020), of them, 3.8% (345 species, 114 genera, 14 families) are known from India (Mandal 2018a, b, 2019). They are widespread and found everywhere, even in the Antarctic and Arctic (Christiansen and Bellinger 2003). They inhabit all habitats like mosses, under stones, in caves, in ant and termite nests, and also in the intertidal zone on the coast, on the surfaces of lakes and ponds, or snowfields, except the open oceans and deep areas of large lakes (Hagvar 1983; Rusek 1998; Christiansen and Bellinger 2003). They are specialized feeders on soil microbiota and play significant roles in the breakdown of leaf litter control aiding in the process of humification and enhancing soil fertility (Parkinson 1983). Collembolans are bio-indicator of soil health as they are extremely susceptible to changes in soil conditions (Ponge 2014).

13.1.3 Class Protura

Protura include tiny apterygote insects lacking eyes, antennae, and cerci with entognathous mouthparts (Allen 2003; Pass and Szucsich 2011). The global diversity includes 816 described species belonging to 76 genera in 7 families and 3 orders (Galli et al. 2018). Presently only 20 species belonging to 10 genera and 3 families are known from India, restricted to the Western Ghats (Kerala), of which 17 species are endemic (Prabhu 1986; Chandra 2011). They are commonly recorded from forest habitats and found in decaying organic matters, soil, moss, peat, leaf litter, and under bark and rotting wood with sufficient moisture (Pass and Szucsich 2011). They are specialized mycorrhizal feeders and compete for their trophic niche with other soil invertebrates (Bluhm et al. 2019). Proturan assemblages are highly susceptive to biogeochemistry and resource availability to forest disturbances (Sterzyńska et al. 2020).

13.1.4 Class Diplura

Diplura includes small- to medium-sized wingless insects with two cerci at the end of the abdomen and moniliform antennae (Gullan and Cranston 2014). They are abundant in humid places, in soil or under bark, living on decaying vegetation or as predators. The world fauna of Diplura comprises 976 species, and 18 species represent the Indian fauna in 9 genera under 4 families, of which 12 species are endemic (Mandal 2010a, b; Chandra 2011; Yadav 2017a, b, 2018).

13.1.5 Class Insecta

13.1.5.1 Order Archaeognatha

Archaeognatha (earlier Thysanura with families Machilidae and Meinertellidae) are medium-sized, wingless insects with multisegmented antennae, monocondylic mandibles, and mouthparts ventrally projecting which can be partially retracted into the head (Gullan and Cranston 2014). They are found hiding under bark, rock crevices, and litter and mostly feed on algae, lichens, and vegetable debris. Globally, 513 species are known, of them, 11 species belonging to 6 genera and 2 families are distributed in India (Mandal 2010a, b; Chandra 2011; Zhang 2013a, b).

13.1.5.2 Order Zygentoma

Zygentoma includes medium-sized wingless insects with three long caudal filaments and commonly known as bristletails and silverfish (Sturm 2003). They prefer both humid and dry environments and live freely or as nest associates. Free-living forms usually found in the forest floor or under bark and rocks. Several silverfish species live in association with ant colonies symbiotically (Molero-Baltanas et al. 2017). Globally, 564 species have been described, of which 29 species belonging to 16 genera and 3 families are reported from India (Hazra and Mandal 2007; Zhang 2013a, b).

13.1.5.3 Order Ephemeroptera

Ephemeroptera (mayflies) are found in all sorts of freshwater habitats (ponds, lakes, streams, rivers, and springs), with few species in the Arctic and hill areas above the tree line. They are susceptible to oxygen depletion, acidification, and various contaminants, including metals, ammonia, and other chemicals in flowing waters (Hubbard and Peters 1978; Moog et al. 1997; Hickey and Clements 1998; Jacobus et al. 2019). Therefore, they are recognized as keystone species and water quality indicators, thus used in biomonitoring (Menetrey et al. 2008). Of 3700 globally described species, 152 species belonging to 60 genera, 15 families, and 4 suborders are distributed in India (Sivaramakrishnan 2016; Selvakumar et al. 2019; Jacobus et al. 2019).

13.1.5.4 Order Odonata

Odonate larvae live in aquatic environments, and adults remain in a terrestrial environment. The order includes three suborders Zygoptera (damselflies), Anisoptera (dragonflies), and Anisozygoptera (living fossil) (May 2019). Globally

6312 species of odonates are known (Schorr and Paulson 2020), of which 496 species (including subspecies) in 153 genera and 17 families are distributed in India (Subramanian and Babu 2020). Odonates are flagship taxa of freshwater ecosystems and are highly specific to their habitat, therefore frequently utilized as indicator species to evaluate the health of their immediate environment (da Silva Monteiro Jr et al. 2013). They are predators of disease vectors and agricultural pests, and also, their larvae are essential as predators in aquatic ecosystems (May 2019).

13.1.5.5 Order Orthoptera

Orthoptera includes devastating pests such as grasshoppers, locusts, and singing insects such as crickets and katydids in two suborders Caelifera and Ensifera (Gullan and Cranston 2014; Song 2018). The global diversity comprises 28,650 valid species (Cigliano et al. 2020), of which 1166 species/subspecies belonging to 449 genera and 22 families are distributed in India (Gupta and Chandra 2019a, b). They are an essential component of grassland fauna in terrestrial ecosystems (Latchininsky et al. 2011). Recently an outbreak of desert locusts, *Schistocerca gregaria* (Forskal), was found severely damaging crops in Northern India (Joshi et al. 2020). Sound production is a unique and diverse behaviour among Orthopterans and plays a crucial role in reproduction (Robinson and Hall 2002).

13.1.5.6 Order Phasmida

Phasmids (=Phasmatodea) are nocturnal, phytophagous, and exopterygote insects and mimic with living or dead twigs and leaves (Bradler and Buckley 2018). They are phytophagous pests of agricultural and timber crops and inhabit tropical, subtropical, and temperate forests, savannas, and grasslands (Baker 2015). Globally, 3350 species have been discovered, of which 140 species belonging to 45 genera and families are distributed in India (Chandra 2011; Zhang 2013a, b; Srinivasan et al. 2018; Brock et al. 2020).

13.1.5.7 Order Embioptera

Embioptera (webspinner) are distributed chiefly in tropical and subtropical regions, with few species from the Mediterranean and semi-arid regions (Büsse et al. 2015). They live in small groups, making tunnels in the soil, under stones, and leaf litter and feed on parts of plant origin, preferably dead leaves; some species also feed on mosses and lichens. As their economic or ecological impact on human life is less known, they play a part in the forest recycling system (Poolprasert 2012). Males are mostly winged, whereas females are wingless and gregarious and live in silken tunnel built by them in litter under the bark or soil (Kapur and Kripalani 1957). Globally, 457 species are described (Zhang 2013a, b), of which 32 species belonging to 6 genera and 2 families (Embiidae, 3 genera, 12 species; Oligotomidae, 3 genera, 20 species) are known from India (Ross 1950; Chandra and Dawn 2014; Gupta et al. 2019).

13.1.5.8 Order Plecoptera

Plecopterans (stoneflies) are soft-bodied insects with their adults having two pairs of unequal wings with complex venation. They live in and around water streams of cold temperate climate, representing about 10% of the invertebrate fauna of rocky streams (Thorp and Rogers 2015). The larval forms are strictly aquatic, dwell under stones in running water streams with high oxygen, and feed upon aquatic flora, whereas adults are terrestrial. Some of the families are commonly named based on their habitat: Pteronarcyidae (salmonflies), Peltoperlidae (roach flies), Perlodidae (springflies and stripetails), Chloroperlidae (sallflies), Taeniopterygidae (winter stoneflies), Capniidae (snow stoneflies), Leuctridae (needle flies), and Nemouridae (forestflies) (Kondratieff 2008). Stoneflies are represented by 3700 species in 16 families (DeWalt et al. 2019). From India, 146 valid species belonging to 27 genera under 8 families, nearly 3.9% of their global diversity and 29.1% of species diversity in Asia-Tropical, including 90 endemic species, have been reported so far (Chandra et al. 2019b).

13.1.5.9 Order Dermaptera

Dermaptera (earwigs) are nocturnal and found in soil, under tree barks, stones, and bricks and are associated with warm, somewhat humid, climates (Hass 2018). They feed on dead and decayed organic matter as scavengers. Some feed upon living plant tissues, and some are carnivorous on other arthropods. They are spread worldwide with maximum diversity in tropical and subtropical regions (Naegle et al. 2016). Globally, 2375 valid species in 311 genera and 19 families have been described (Hopkins et al. 2020), of which 284 species belonging to 72 genera and 7 families are distributed in India (Srivastava 2013; Chandra et al. 2019c).

13.1.5.10 Order Mantodea

Mantodea (praying mantis) is a well-known group of fascinating and predatory insects, recognizable by their mobile triangular head and large raised raptorial forelegs for seizing prey (Loxton and Nicholls 1979). Globally, 3049 species in 639 genera and 33 families have been described (Otte et al. 2020), of which 184 belong to 73 genera and 11 families (Chandra 2011; Mukherjee et al. 2014; Ghate et al. 2020). They are valuable agents of biological pest control (Symondson et al. 2002). The prey species range from flies, crickets, moths, caterpillars, locusts, and many other insects to vertebrates like amphibians, birds, snakes, and lizards (Nyffeler et al.

2017; Valdez 2020). Mantises are well known to catch small birds, especially hummingbirds, as they fly midair (Fisher 1994; Hildebrand 1949). They are the only known insect to kill their prey with their legs (Rivera and Callohuari 2019). There is only a record of *Hierodula patellifera* (Serville), predating on crimson-backed sunbird from India (Browne 1899). Some of the mantises are pollen feeders, wherein pollen of flowering plants as a potential alternative source of food (Beckman and Hurd 2003).

13.1.5.11 Order Blattodea

Cockroaches together with termites form Blattodea (Beccaloni and Eggleton 2011). Globally, Blattodea includes 7779 valid species. Of them, 4837 are cockroaches (Beccaloni 2014) and 2942 are termites (Beccaloni and Eggleton 2011).

Cockroaches are nocturnal and worldwide in distribution except in Antarctica but are most diverse in tropical and subtropical regions. They occur in a wide variety of habitats, from deserts to semi-aquatic environments. However, the most significant numbers of species live in hot, humid forests (Djernaes 2018). They are detritivores and depend on dead plant matter. Indian diversity includes 181 species of cockroaches belonging to 72 genera under 17 subfamilies and 6 families, including 89 endemic species (Gupta and Chandra 2019b).

Termites are social insects and the essential components of the forest ecosystem in tropical and subtropical areas (Eggleton 2000; Shanbhag and Sundararaj 2013). Indian diversity is represented by 295 species in 52 genera with high-level endemism of approximately 177 species. They are well known for their capacity to damage wood and wood products of all kinds. Termites are ecosystem engineers and help in sustaining soil productivity and rehabilitating degraded soils in tropical agroecosystems (Jouquet et al. 2011).

13.1.5.12 Order Psocoptera

Psocopterans (bark lice or booklice) are soft-bodied species that usually live in tree trunks, under barks, and weathered walls and primarily feed on starch grains and bookbinding glue (Green and Turner 2004) and also on microepiphytes (fungi, algae, and lichens) and general debris (Thornton 1985). Economically, they are essential commodities, and high moisture and mold contamination encourage psocid infestation (Semple 1986). Some psocids are a pest of stored grain (Stejskal et al. 2015); others cause considerable loss to libraries and books. They also help in decomposition by feeding on detritus; the nymph of some form are wood-boring (Smithers 1995). Globally, 5611 species have been described (Johnson et al. 2020; Zhang 2013a, b), of which 126 species are distributed in India.

13.1.5.13 Order Phthiraptera

Phthirapterans (chewing and sucking lice) are obligatory ectoparasites, infesting warm-blooded hosts like birds and mammals. This order includes four suborders, namely, Anoplura, Rhynchophthirina, Ischnocera, and Amblycera. Anoplurans are obligatory ectoparasites of mammals, except for Chiroptera, Edentata, Pholidota, Cetacea, Proboscidea, and Sirenia (Kim and Ludwig 2008). Approximately 65% of species of mammals are believed to harbor sucking lice (Adhikary and Ghosh 1994). The chewing or biting lice in the other three suborders are host-specific and sensitive to the temperature having a narrow range of preference (Ash 1960). Globally about 5316 species have been described, of which 466 (16 endemics to India) species are known from India (Galloway 2018; Chandra 2011).

13.1.5.14 Order Thysanoptera

Thysanoptera (thrips) are among the smallest (1.5–3 mm) of the winged insects. They are an economically significant group and cause plant galls and leaf rolls, thus reducing seed production and disfiguring leaves, flowers, and fruits. Some transmit plant viruses, a few preys on destructive mites and scale insects, and many of them may support the pollination of flowers (Mound 2018). Globally 6288 species have been described so far (Thrips Wiki 2020), of which 754 species in 260 genera are distributed in India (Tyagi and Kumar 2016).

13.1.5.15 Order Hemiptera

Hemiptera comprises four suborders, Auchenorrhyncha (cicadas, leafhoppers, treehoppers, planthoppers, and spittlebugs), Sternorrhyncha (aphids, whiteflies, and scale insects), Coleorrhyncha (moss or beetle bugs; not recorded in India), and Heteroptera (true bugs) (Henry 2017). They are hemimetabolous, some feed on plants (some are serious pests), some are predators, and some are hematophagous. Generally, they live a terrestrial life, whereas some species adapted to an aquatic environment. Auchenorrhynchans are exclusively terrestrial, but infra-orders Gerromorpha and Nepomorpha (in Heteroptera) are aquatic and semi-aquatic and inhabit freshwater or brackish and sea waters (*Halobates* spp.). Globally 107,180 species of this order are known with maximum diversity in Heteroptera (45,254 species) (Henry 2017), followed by comprising of Sternorrhyncha (18,690 species) (Hardy 2018), Auchenorrhyncha (43,204 species), and Coleorrhyncha (30 species) (Bartlett et al. 2018). A total of 6479 species represent Indian diversity in 92 families (Chandra et al. 2018c).

13.1.5.16 Order Hymenoptera

The members of this order may be parasitic or nonparasitic, carnivorous, phytophagous, or omnivorous and are perhaps the most beneficial to human beings as pollinators of flowering plants, producers of wax and honey, and parasites of destructive insects, as well as the best-known members of the social insects-ants, bees, and wasps. Hymenoptera is divided into two suborders, Symphyta (sawflies) and Apocrita, later subdivided into "Aculeata" (stinging wasps, bees, and ants) and Parasitica (parasitoids). The main diagnostic characteristics of Hymenoptera are membranous wings with reduced venation mostly; both fore and hind wings are coupled by means of hooks (hamuli); mouthparts adapted for biting or chewing or modified for sucking also; and ovipositor in females is well developed and variously modified for sawing, piercing or stinging, and egg-laying. As holometabolous insects, the lifecycle comprises egg, larval, pupal, and adult stages. The global diversity of hymenopteran fauna is about 154,067 species (Zhang 2013a, b), of which approximately 10,605 species are known from India (Chandra et al. 2018a).

13.1.5.17 Order Strepsiptera

Strepsiptera (twisted-winged parasitoids) comprises holometabolous insects, which are obligate entomophagous endoparasitoids. Adults have a highly specialized morphology, extreme sexual dimorphism, and unique biology and spend most of their lifecycles as internal parasites of other insects. Globally 627 species in 15 families (Kathirithamby 2018; Cook 2019) are known, of which 28 species (4.5%) are distributed in India (Chandra 2011; Cook 2019).

13.1.5.18 Order Coleoptera

Coleoptera is the most species-rich order on this planet. This much diversity is the outcome of some 250 million years of evolution since the earliest beetle fossils found in the Permian period. The beetles are present virtually in every habitat (except sea and polar regions), including freshwater and coastal habitats; on vegetative foliage such as trees and their bark, flowers, leaves, and underground near roots; and even inside plants in galls, including dead or decaying ones (Gullan and Cranston 2014). In the ecosystem, they immensely perform several ecological and functional roles. The species in this order are of great commercial significance and are both beneficial and harmful to humankind. They are serious pests of various agricultural and forest crops and also act as biological control agents like ladybird beetles (Coccinellidae) and dung beetles (Scarabaeidae).

Exploration of beetle fauna is not equal in every part of the globe, so a higher number of species are expected as this is the most diversified insect order. Grove and Stork (2000) hypothesized that about 70–95% of all the beetle species are yet to be discovered and described and also emphasized that it would take 200 years to explore the entire beetle fauna of the world. As per estimate made by Zhang (2013a, b), around 386,755 extant species belonging to 29,595 genera and 176 families under four suborders (Archostemata, Myxophaga, Adephaga, and Polyphaga) are known globally (Bouchard et al. 2017). From India, more than 22,334 species are known in 114 families (Chandra et al. 2018a, b). Seven families are highly diverse—Staphylinidae, Scarabaeidae, Carabidae, Chrysomelidae, Curculionidae, Elateridae, and Tenebrionidae.

13.1.5.19 Orders Neuroptera, Megaloptera, and Raphidioptera

Orders Neuroptera (antlions, dusty wings, lacewings, mantidflies, owlflies), Megaloptera (alderflies, dobsonflies), and Raphidioptera (snakeflies) together comprise superorder Neuropterida (Aspöck 2002; Whiting 2002b; Wiegmann et al. 2009; Winterton et al. 2010, 2018). The larvae are terrestrial or aquatic or predaceous or parasitic. Neuropterida, with a total of 6556 species worldwide, are primitive insects with complete metamorphosis. There are 5917 species of Neuroptera, 386 species of Megaloptera, and 253 species of Raphidioptera known globally, of which 327 species of Neuroptera, 30 species of Megaloptera, and 5 species Raphidioptera are distributed in India (Aspöck 2002; Chandra 2011; Zhang 2013a, b; Oswald 2020). Most members are exceptionally predaceous insects; only a few species have been of practical use in the biological control of agricultural insect pests such as aphids, coccids, thrips, moths, and mites.

13.1.5.20 Order Trichoptera

Trichoptera (caddisflies) comprises a group of holometabolous insects that are closely related to the order Lepidoptera. The juvenile stages remain dependent on the aquatic environment. They are generally plentiful in freshwater ecosystems such as springs, mountain streams, rivers, the splash zones of waterfalls and marshy wetlands, along shorelines as well as in the depth of lakes, and temporary waters. The caddisflies are considered to be excellent bioindicators of windstorm activity, hydromorphological degradation, and temperature changes (Kalaninová et al. 2014). With a high diversity of species having both cases- and shelter-constructing larvae, they act as useful indicators of organic pollution. Immature stages of caddisflies have been used extensively in biomonitoring assays with indicator species, selected communities or assemblages of species, or more broadly based family level identification of species being used to assess the health status of aquatic ecosystems. Globally, 16,266 species belonging to 632 genera and 63 families (Morse 2020) are known, of which 1299 species belonging to 97 genera and 27 families have been recorded from India (Kaur and Pandher 2020; Pandher et al. 2021).

13.1.5.21 Order Lepidoptera

Lepidopterans include primarily phytophagous and most visually appealing insects, butterflies, and moths (Gullan and Cranston 2014). Butterflies represent 18,768 species belonging to 1815 genera in the superfamily Papilionoidea, further divided into six families—Papilionidae, Hesperiidae, Pieridae, Riodinidae, Nymphalidae, and Lycaenidae (van Nieukerken et al. 2011; Zhang 2013a, b). From India, 1501 species of butterflies are reported (Kunte 2000). They are economically significant and serve as pollinators and are appreciated for their aesthetic value (Chakravarthy et al. 1997). They are also good indicators of anthropogenic disturbance and habitat quality as they are sensitive to changes in the environment (Sparrow et al. 1994).

Although moths (139,655 species) contribute about 88% of the total Lepidoptera, they are still less popular, probably due to their predominantly nocturnal habit and drab color, of which 12,193 species (8.8% of global diversity; ZSI) are from India. Moths are considered to be very sensitive to vegetation alterations and climate change, thereby making it essential taxa for monitoring climate and habitat changes, which is an urgent need of the hour to conserve the world's biodiversity. As there is enough evidence of climate change, baseline data preparation is the first step for knowing about the region's floral, faunal, or habitat diversity.

13.1.5.22 Order Diptera

Diptera includes two-winged flies, such as midges, gnats, mosquitoes, horse flies, black flies, fruit flies, and house flies. They play significant roles in pollination, as pests of various agricultural and forest crops, as agents of disease transmission and biological control, as invasive alien species, and as scavengers and decomposers. They are worldwide in distribution, even in Antarctica and in practically every habitat except the open sea and inside glaciers (Courtney et al. 2017). With over 157,971 described species globally, they are next to Coleoptera and Lepidoptera in insect diversity (Courtney et al. 2009, 2017). More than 7382 species belonging to 1345 genera are known to be from India, with 30.2% (2183 species) endemism at the species level and 8.31% (110 genera) endemism at the generic level (Banerjee et al. 2018, 2022).

13.1.5.23 Order Siphonaptera

The order Siphonaptera (fleas) are hematophagous parasites of birds and mammals—including human beings. Roughly 94% of the species are associated with mammalian hosts, and the remaining species are infesting birds (Whiting et al. 2008). Adult fleas must feed on their host's blood for egg production so that they can maintain a free existence for a considerable length of time when in search of a host. Fleas are the principal pests of humans and domestic animals and vectors of disease. Globally about 2575 species and subspecies are currently placed in 16 families and 246 genera (Lewis 1998; Whiting et al. 2008). Indian diversity includes 51 species and subspecies belonging to 8 families and 24 genera (Sharma and Chandra 2013; Chandra et al. 2018a, d).

13.1.5.24 Order Mecoptera

Mecoptera (scorpionflies) are holometabolous insects having the male ninth abdominal segment (genital segment) in the family Panorpidae upturned and enlarged, protruding like stingers of a scorpion (Whiting 2002a, b). The mecopterans in the family Bittacidae are also known as hanging flies because some species of the genus *Bittacus* hang from the vegetation with the help of their fore and mid legs (Whiting 2002a, b). Globally 737 described species in 9 families and 382 genera worldwide (Bicha 2018) are known, of which 23 species belonging to 2 genera and 2 families (Bittacidae and Panorpidae) are distributed in India (Penny and Byers 1979; Chandra 2004).

13.2 Insect Biodiversity in Ecosystems and Biogeographic Zones

13.2.1 Aquatic Ecosystem

13.2.1.1 Freshwater

Freshwater habitats cover less than 1% of Earth's surface, and India has 4% of the world's freshwater resources. They include lakes and ponds, rivers, streams, springs, wetlands, etc. The National Wetland Inventory and Assessment by the Ministry of Environment Forest and Climate Change, Government of India, estimates that 10.56 million hectares of inland wetlands exist in India, comprising 6.62 million hectares of natural wetlands and 3.94 million hectares of human-made wetlands. The global freshwater biodiversity includes over 140,000 faunal species as per global assessment of the biodiversity of freshwater ecosystems.

In India, 9456 freshwater animal species are known; of them, phylum Arthropoda alone represents 5923 species or about 62.6% of the total (Chandra et al. 2017). Insect diversity in Indian freshwater includes more than 5014 species/subspecies in 9 major groups (Tables 13.2 and 13.3): aquatic Diptera (1588), caddisflies (1299), beetles (776), dragon and damselflies (494), aquatic bugs (325), mayflies (152), stoneflies (146), Hymenoptera (150), and Lepidoptera (moths: 80). The diversity in these ecosystems is severely affected by overexploitation, water pollution, flow

Table 13.3 Insect diversity (Arthropoda: Hexapoda) at ecosystem and biogeographic level in India

Classes/orders	Freshwater	Soil	Mangrove	Medical and veterinary	Island	Trans-Himalaya	Himalayas	Desert
Collembola	–	345	28	–	18	30	147	16
Protura	–	20	–	–	–	–	–	–
Diplura	–	19	–	–	–	–	2	–
Insecta								
Archaeognatha	–	11	2	–	2	1	9	–
Zygentoma	–	29	3	–	1	–	17	3
Ephemeroptera	154	–	–	–	3	13	49	1
Odonata	496	–	47	–	78	47	257	58
Orthoptera	–	541	48	–	115	24	497	130
Phasmida	–	140	1	–	11	1	37	–
Embioptera	–	32	–	–	2	1	7	–
Plecoptera	146	–	–	–	–	15	89	–
Dermaptera	–	284	10	–	25	7	152	5
Mantodea	–		8	–	12	4	65	16
Blattodea (cockroaches)	–	181	5	181	16	3	44	6
Blattodea (termites)	–	295	15	–	36	–	115	47
Psocoptera	–	–	1	–	–	7	40	–
Phthiraptera	–	–	2	466	4	46	130	53
Thysanoptera	–	–	2	–	32	88	222	30
Hemiptera	325	–	168	–	407	648	1841	143
Hymenoptera	150	2952	172	–	367	585	3054	246
Coleoptera	776	8862	340	6	936	93	10,533	326
Strepsiptera		–		–	–	–	3	–
Neuroptera	–	–	7	–	15	1	124	17
Megaloptera	–	–	–	–	–	–	14	–

(continued)

Table 13.3 (continued)

Classes/orders	Freshwater	Soil	Mangrove	Medical and veterinary	Island	Trans-Himalaya	Himalayas	Desert
Raphidioptera	–	–	–	–	–	–	1	–
Trichoptera	1299	–	–	–	21	170	425	1
Lepidoptera (butterflies)	–	–	143	–	301	90	1249	138
Lepidoptera (moth)	80	–	200	–	796	190	4195	161
Diptera	1588	–	259	1614	372	213	1698	183
Siphonoptera	–	–	–	51	2	14	38	–
Mecoptera	–	–	–	–	–	–	10	–
Total	5014	13,711	1461	2317	3572	2291	25,064	1580

modification, destruction or degradation of habitat, invasion by exotic species, and hydropower (Gatti 2016).

13.2.1.2 Marine (Coastal)

Because of low concentrations of calcium in seawater, insects' diversity in marine habitats is limited, and they failed to establish themselves in the world's seas and oceans (Cheng 1976). As per Cheng (1976), there are no marine insects that remain submerged throughout their lives. Marine water striders in the genera *Halobates* spp. (ten species; Andersen and Foster 1992; Radhakrishnan and Thirumalai 2004), *Halovelia* spp., *Hermatobates* spp., and *Asclepios* spp. have been reported from India and the Indian ocean (Cheng 1976). Apterygote genus *Oudemansia* sp. (Collembola) and dipteran genus *Culicoides* spp. have also been recorded from India marine waters (Sen and Das Gupta 1959; Cheng 1976).

13.3 Soil (Belowground)

A large portion of our faunal communities remains below-ground, and the activities of these diverse soil-dwelling organisms and their interaction with the abiotic environment affect the structure and functioning of the soil ecosystem (Wardle et al. 2004). Interactions between soil-dwelling organisms and plants affect plant growth and diversity and thus are considered as the root of sustainable agriculture (Neher and Barbercheck 2019). As per estimates, in India, over 13,711 insect species depend directly or indirectly on the soil ecosystem, comprising 60% of the overall soil faunal diversity of the country (22,586 species) (Chandra et al. 2019e, 2020c) (Tables 13.2 and 13.3). Springtails, proturans, diplurans, beetles, bugs, ants, termites, and crickets are ubiquitous among the soil microarthropods (Table 13.3).

13.4 Mangrove Forests

Mangrove forests grow under an environment of high salinity, extreme tides, strong winds, high temperatures, and muddy and anaerobic soils (Kathiresan and Bingham 2001). They are among the world's most productive ecosystems and include a plant community of trees, bushes, and shrubs which grow within the inter-tidal zones of the coastal estuary and riverine areas, between the level of high water of spring tides and a level close to but above mean sea level (Macnae 1968; Rajpar and Zakaria 2014). They have a vital ecological role in protecting the land shores from wind, waves, and flow (Veenakumari and Prashanth 2009). This ecosystem is severely threatened by urbanization and the expansion of agricultural and aquacultural practices.

The mangroves are stretched along the coastline of 12 states and union territories and are classified into 3 major zones: Eastern Coast Mangroves, Western Coast Mangroves, and Insular Mangroves (Andaman and Nicobar Islands) with 46 true mangrove plant species (Ragavan et al. 2016; Mandal and Naskar 2008). A total of 4822 faunal species belonging to 21 phyla have been recorded from these ecosystems in India (Chandra et al. 2019a), of which 30.3% (1461 species) belong to different insect groups (Tables 13.2 and 13.3). Along with other faunal groups, insects also play indispensable roles in the ecology and contribute to the unique nature of these habitats (Kathiresan and Bingham 2001). Insects are associated with the mangals as permanent residents or only as transient visitors (Kathiresan and Bingham 2001).

13.5 Biogeographic Zones

13.5.1 Himalayan Ecosystems

The Himalayas covers ~6.4% (210,662 sq. km.) of India's broad geographical area, forming the group of mountain ranges lying south of the Great Himalaya and the Siwalik Ranges and Lesser Himalayan Ranges. The Himalayas is broadly classified into four regions Northwest, West, Central, and East Himalayas. Parts of Himachal Pradesh and Jammu and Kashmir come under Northwest Himalaya, Uttarakhand and some area of Himachal under West Himalaya, hills of Darjeeling (West Bengal) and Sikkim under Central Himalaya, and the state of Arunachal Pradesh under East Himalaya.

Insect diversity in this region represents over 81% (25,064 species) of the total Himalayan faunal diversity (30,615 species) and 37.9% of the total insect diversity of India (Chandra et al. 2018a; Chandra et al. 2020a). Central Himalaya has the highest insect diversity with 12,053 species/subspecies, followed by West Himalaya (10,002), Northwest Himalaya (6445), and East Himalaya (3819) (Chandra et al. 2018a). The maximum number of species is reported in the order Coleoptera (10,533 species/subspecies), followed by Lepidoptera (5444: 1249 butterflies; 4195 moths), Hymenoptera (3054), Diptera (1698), Hemiptera (1841), Orthoptera (454), Trichoptera (425), Odonata (257), Thysanoptera (222), Blattodea (159: 115 termites, 44 cockroaches), Dermaptera (152), Phthiraptera (130), Neuroptera (124), Plecoptera (89), Mantodea (65), Ephemeroptera (49), Psocoptera (40), Siphonaptera (38), Phasmida (37), Zygentoma (17), Megaloptera (14), Mecoptera (10), and less than 10 species of Archaeognatha (9), Embioptera (7), and Strepsiptera (3).

13.5.2 *Trans-Himalaya (Cold Desert)*

Trans-Himalaya is the high-altitude cold desert and arid mountain areas in the districts of Ladakh and Kargil (Jammu and Kashmir), Lahaul and Spiti valleys, Pooh tehsil (Himachal Pradesh), small areas in the rain shadows of Nanda Devi range (Uttarakhand), and Kangchenjunga range (Sikkim) (Mehta and Julka 2001). They comprise a complex network of barren mountain ranges, lying in the north of the main Himalayan ranges, and include Zaskar, Ladakh, and Karakoram ranges (Mani 1974a, b). Because of dry and cold climatic conditions, this zone is termed a high-altitude cold desert. Trans-Himalaya in India covers a total area of ~1,84,823 sq. km., accounting for 5.62% of the country's landmass (Rodgers and Panwar 1988; Rodgers et al. 2002), further differentiated into Ladakh Mountains, Tibetan Plateau, and TH-Sikkim (Rodgers et al. 2002). Over 69% (2291 species) of total faunal diversity from Indian Trans-Himalaya (3324 species) include insects in different groups (Chandra et al. 2019f). A total of 1031 species are recorded from Ladakh Mountains, 833 from Trans-Himalaya-Sikkim, and 811 from Tibetan Plateau (Chandra et al. 2020a).

13.5.3 *Islands (Andaman and Nicobar Islands)*

The Andaman and Nicobar Islands comprise an arcuate series of more than 572 islands, islets, and rocks, with 8249 sq. km. in the Bay of Bengal with a coastline of 1962 km. This archipelago supports a unique biodiversity due to its geographical position, tropical climate, and long isolation from the Indian subcontinent. Over 11,009 faunal species in 24 different phyla have been documented from these islands (Chandra and Raghunathan 2018). Over 32.4% (3572 species) are insects alone (Chandra et al. 2018b). With only 0.25% of India's geographical area, the islands harbor 5.4% of the country's overall insect diversity.

13.5.4 *Thar Desert*

Indian Desert spreads over an area of 215,757 sq. km. in the states of Rajasthan (Thar Desert) and Gujarat (Kachchh), comprising 6.56% of the total landmass of the country. Due to the extreme environment, the Thar Desert is considered a delicate ecosystem. The minor factors can create an imbalance in the ecosystem. The biodiversity in the Thar may not be comparatively rich, but it is unique and constitutes an invaluable stock of rare and resistant germplasm. The database by ZSI suggests that all the dominant invertebrate and vertebrate groups and even microscopic protozoans are found in the region. The animal life in the deserts survives by hiding in the burrows, long tunnels, under stones, plant leaves and roots, ponds, puddles, and larger reservoirs and lakes. Indian desert includes 1580 species belonging to 947 genera under 16 orders of which Coleoptera (326 species), Lepidoptera (299 species), Hymenoptera (246 species), Diptera (183 species), Hemiptera (143 species), and Orthoptera (130 species) remain the major groups.

13.6 Ecosystem Services Provided by Insects

13.6.1 Pollination

Pollination is the transfer of pollen among male and female parts of flowers to facilitate fertilization and reproduction. Notwithstanding self-pollination and wind pollination, most agricultural and wild plants depend on animals such as flies, wasps, butterflies, moths, beetles, weevils, thrips, ants, midges, bats, birds, primates, marsupials, rodents, and reptiles for pollination. Among them, bees (Hymenoptera) are the most effective pollinators of cultivated and wild plants (Burkill 1906, 1908; Roubik 1995; Garibaldi et al. 2013; Rader et al. 2016; Matias et al. 2017). As per the assessment report on Pollinator, Pollination, and Food Production by Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services report in 2016, animal pollination contributes to nearly 5–8% of global crop production, with an annual market value of 235–577 billion dollars worldwide (IPBES 2016).

13.6.1.1 Hymenoptera (Bees and Wasps)

Globally, over 20,355 bee species (Hymenoptera: Apoidea) are known (Ascher and Pickering 2019), of which 766 species are distributed in India (Saini and Chandra 2019). Many bees are pollen specialists on particular kinds of flowers. Even among generalists, different types of bees have different but strong preferences. Bee species specialize in the collection of pollen and nectar and have a direct relation to floral morphology. Previously, the main focus has been on domesticated bees such as *Apis mellifera* Linnaeus 1758, and *Apis cerana* Fabricius 1793, with some bumblebees and stingless bees for pollination potential. Now wild bee pollination has gained more attention, because of the dramatic decrease in honey bee populations due to mite infestations, especially in the north-temperate climates. There are shreds of evidence for various crops for which honey bees are poor pollinators compared to wild bees (Thorp and Loper 1984).

Twenty-eight species of fig wasps (Hymenoptera: Agaonidae) are reported to pollinate 25 species of *Ficus* trees, the tropical forests’ keystone species (Shilpa and Santhosh 2019). The potential of orders Hemiptera and Diptera as pollinators is briefly given by Hassan et al. (2019) and Sengupta et al. (2019).

A wild bee (*Bombus* sp.) in the Indian Himalayan Region

13.6.1.2 Thrips

Thrips are also reported to pollinate plants such as cacao, sugarbeet, alfalfa, a few legumes, oil palm, and certain flower species of the families Asteraceae, Fabaceae, Rubiaceae, and Solanaceae (Varatharajan et al. 2016; Varatharajan and Rachana 2019).

13.6.1.3 Butterflies and Moths

Butterflies are considered to be pollinators of various plants. However, it is believed that they visit flowers less frequently than bees and deposit less pollen per visit for most plant species (Barrios et al. 2016). Some studies on butterflies and moths suggest that these groups carry pollen farther than other insects, and this long-distance pollen transfer could have significant genetic consequences for plants. Singh (2019) identified 67 species of moths in families Sphingidae, Noctuidae, Notodontidae, Geometridae, and Erebidae to be playing an essential role in the pollination of different plant species in the Indian Himalayan Region.

13.6.1.4 Beetles

Beetles have also been widely recognized to visit flowers for nectar, pollen, food materials, mating, and oviposition. Corlett (2004) estimated that beetles are the second largest group of insects after bees, responsible for pollination in the oriental region. The beetles in the suborder Polyphaga visit flowers, and among them, the families such as Scarabaeidae, Mordellidae, Chrysomelidae, Nitidulidae, Staphylinidae, Curculionidae, and Cerambycidae were found to be potential pollinators (Maeto et al. 1995; Das et al. 2019). Armstrong and Drummond (1986) reported that cultivated nutmeg trees (*Myristica fragrans* Houtt) in southern India are pollinated mainly by an anthicid flower beetle, *Formicomus braminus* (Bonadona). Sivadasan and Sabu (1989) found that *Haptoncurina motschulskii* (Reitter) (Nitidulidae) is an effective agent of cantharophily in *Amorphophallus hohenackeri* (Schott) in Southwest India. Devy and Davidar (2003) reported that beetles pollinate all three trees in the family Annonaceae.

13.7 Forest Insects

Forests are complex ecosystems that provide valuable products, such as timber, fuelwood, and fiber, and contribute to the resources of rural inhabitants (FAO 2009). They also render several ecosystem services such as habitat for plants and animals, aesthetic landscapes, pollution reduction, biomass production, pollination, seed dispersal, fire regulation and mitigation, pest regulation of native and invading insects, carbon sequestration, livestock forage, resistance to wind storms, and biodiversity that improve quality of life (Kline et al. 2007; Brockerhoff et al. 2017). Insects are a natural and necessary element of healthy forest and habitat provisioning services. Beeson (1941) defined a forest insect as an insect that lives in the forest. Most forest insects are beneficial, help decay dead vegetation, and release nutrients for plants (Morrison et al. 2007). Many are food for wildlife, and some prey on other insects that are harmful to plants keeping pest outbreaks in check (Morrison et al. 2007). The insect diversity in tropical forest is higher in temperate and boreal forests (Nair 2007).

In the case of Indian forest insects, Beeson (1941) carried out the most extensive work to date and studied over ~4300 species. Later a list of ~16,000 species of forest insect with their host plants (~2140 species) from India and adjacent countries was published by Bhasin and Roonwal (1954), Bhasin et al. (1958), and Mathur and Singh (1959, 1960a, b, c, 1961a, b) in nine volumes. Further, Browne (1968) also published an annotated list of Pests and Diseases of Forest Plantation Trees in the British Commonwealth.

A global review of forest pests and diseases (Food and Agriculture Organization of the United States 2009) reported a total of 110 species of insects as serious forest pest of natural, planted, broadleaf, and conifer forests in Asia and the Pacific in five countries: India, China, Mongolia, Thailand, and Indonesia. Coleoptera and Lepidoptera are two major pest orders reported in these areas. These pest species attack trees, causing discoloration of foliage, defoliation, or both, resulting in dead and down trees and visible damage to forests, which, in turn, may reduce the benefits derived from the forest and its products.

- Several beetles feed on forestry plantation wood. Long-horned beetles (Cerambycidae) feed on freshly felled timber with intact bark, and the beetles of the families Ptinidae (Anobiinae), Bostrichidae, Brentidae, and Curculionidae (Scolytinae, Platypodinae) feed on drier wood. Passalidae, Anthribidae, Lucanidae, and Oedemeridae feed on wet and rotten wood. The most dominant families such as Chrysomelidae, Curculionidae, Scarabaeidae (chafers), and Buprestidae feed on leaves. Scarabaeidae (dung beetles), Tenebrionidae, Cucujidae, and Elateridae feed primarily on the matter on the ground and depend on humus and soil. The predacious beetles in families Carabidae, Cicindelidae, Cleridae, Coccinellidae, and Staphylinidae are dominant in Indian forests. Dermestidae feed on keratinous material. Because of a severe infestation of Sal heartwood borer, *Hoplocerambyx spinicornis* (Newman) [Coleoptera], out of 3.5 million infested trees, 1.59 million trees had to be felled and removed from the worst affected Dindori and Mandla Forest Divisions alone in Madhya Pradesh (Prakasam et al. 2020). Four species of beetles—*Sphenoptera aterrima* Kerremans (Buprestidae), *Cryptorhynchus rufescens* Roelofs (Curculionidae), *Platypus biformis* Chapuis (Curculionidae: Platypodinae), and *Polygraphus longifolia* Stebbing and E.P. (Curculionidae: Scolytinae)—caused massive mortality of pine trees in the Morni Hills of Haryana (Singh et al. 2001; Nair 2007). White grubs (Scarabaeidae: Melolonthinae and Rutelinae) cause damage to teak seedlings, neem, pines, sal, and acacias. *Holotrichia consanguinea* Blanchard and *Holotrichia serrata* Fabricius (Coleoptera: Scarabaeidae: Melolonthinae) are common species found in teak nurseries in India (Nair 2007).
- Lepidoptera (moths and butterflies) is second after Coleoptera in terms of damage caused to trees. The adults are short-lived and feed on nectar and other fluids, while caterpillars feed on foliage. *Hyblaea puera* (Cramer) [teak defoliator], *Eutectona machaeralis* Walker [teak skeletonizer], and *Duomitus ceramicus* (Walker) (=*Xyleutes ceramica* Walker) [bee-hole borer] are the principal pests of teak in Asia. Some species of Pyralidae, Gelechiidae, Blastobasidae, and Oecophoridae bore into young shoots, and some species of Cossidae, Hepialidae, and Tineidae bore into branch wood. Indarbelidae and some species of Tineidae feed on bark. Caterpillars of some species of Pyralidae and Eucosmidae feed on seeds and fruits. Nearly 85 species of lepidopterans have been recorded on teak plantation alone (Nair 2007). *Antheraea mylitta* (Drury) (Saturniidae) is an economically important species commonly known as tasar silkworm, known to produce Tussar silk, a kind of wild silk.
- Termite, as a pest, is capable of causing havoc by destroying wood and wooden structures and live trees. Shanbhag et al. (2013) identified 92 that species are wood-destroying termites representing 22 genera in 5 families: Termopsidae, Kalotermitidae, Rhinotermitidae, Stylotermitidae, and Termitidae.
- The major hemipteran families of forestry importance are Cicadidae, Coccidae, Psyllidae, and Tingidae. In the Indian forests, Cicadas are well-known insects feeding on the sap of tender shoots and twigs of trees, and loud noise produced by male cicadas can be recognized. *Gmelina arborea* Roxb. plantations are facing a greater threat from lace bug *Tingis beesoni* (Drake) (Tingidae), resulting in top

dying of shoots in the tropical forest of Madhya Pradesh (Meshram and Bhowate 2017). *Heteropsylla cubana* Crawford (Psyllidae), an introduced species, caused severe defoliation and extensive damage of young trees *Leucaena leucocephala* (Lam.) in Southern India (FAO 2007). Some of the hemipterans are economically beneficial too, such as *Kerria lacca* (Kerr) (Hemiptera: Kerriidae), native to Asia, which is the primary source of lac, a resin that can be refined into shellac and other products.

- A gall midge, *Asphondylia tectonae* Mani (Diptera: Cecidomyiidae), has been reported to cause stem galls on teak branches (Chavan and Kumar 1998). Grasshoppers and crickets (Orthoptera) are ubiquitous in Indian forests, but their population do not increase in enough numbers to cause severe damage, although sometimes they cause extensive damage to forest tree seedlings in nursery beds.

13.8 Medical and Veterinary Insects

Arthropod-related disorders continue to cause significant health problems to humans, domestic animals, and wildlife. The important insect groups of medical and veterinary significance are Blattodea (cockroaches), Phthiraptera (chewing and sucking lice), Hemiptera (bed bugs and kissing bugs), Coleoptera (blister and rove beetles), Diptera (mosquitoes, sandflies, biting midges, black flies, horse flies, glossinid flies, house and stable flies, latrine flies, myiasis-causing flies), Siphonaptera (fleas), and Hymenoptera (wasps, hornets, velvet ants, ants, bees) (Mullen and Durden 2019).

Insects have profoundly influenced humans as vectors for various deadly diseases and known to transmit protozoans, bacteria, viruses, and nematodes. Malaria, dengue, chikungunya, yellow fever, Japanese encephalitis, lymphatic filariasis, and Leishmaniases are dreadful diseases transmitted by insect vectors. Likewise, livestock scourges such as bovine babesiosis, bovine theileriosis, scabies, pediculosis, and botfly infestations, all of which are caused or transmitted by arthropods, have greatly influenced animal production and husbandry practices. The influential groups causing insect-borne diseases are given in Table 13.4.

13.9 Insects and Food Security (Edible Insects)

In the twenty-first century, efforts are needed to find new and innovative ways of increasing food production to feed the continuously growing population because of the rising cost of animal protein (Payne and van Itterbeeck 2017). Insect consumption is not a new idea in many parts of the world, especially in tropical countries, and expected as a solution for food and feed security in the future (van Huis et al. 2013).

Table 13.4 Medical and veterinary insects of India

Order/family	Common name	Number of species (approximate)
Order Blattodea	Cockroaches	181
Order Phthiraptera	Sucking lice	466
Order Hemiptera		
Cimicidae	Bed bugs	10
Reduviidae: Triatominae	Kissing bugs	7
Order coleoptera		
Meloidae	Blister beetles	3
Staphylinidae	Rove beetles	3
Order Diptera		
Culicidae	Mosquitoes	404
Psychodidae: Phlebotominae	Sand flies	52
Ceratopogonidae	Biting midges	374
Simuliidae	Black flies	69
Tabanidae	Horse flies	247
Glossinidae	Glossinid flies	1
Muscidae	House and stable flies	276
Faniidae	Latrine flies	4
Calliphoridae	Enteric disease, myiasis	63
Sarcophagidae	Myiasis	126
Order Siphonaptera	Fleas	51
	Total	2337

Insects are healthy and nutritious and plentiful in protein and fats and high in calcium, iron, and zinc. They can be utilized as alternatives to animal proteins such as chicken, pork, beef, and even fish. Moreover, insects already form a traditional part of many regional and national diets (Huis et al. 2013). Jongema (2017) listed more than 2111 edible insect species worldwide. They belong to the following groups: Coleoptera (beetles, often larvae) (659), Lepidoptera (caterpillars) (362), Hymenoptera (wasps, bees, and ants) (321), Orthoptera (crickets, grasshoppers, and locusts) (278), Hemiptera (true bugs) (237), Odonata (dragonflies) (61), Isoptera (termites) (59), Diptera (flies) (37), cockroaches (37), and others (9%) (Jongema 2017).

Out of the total 2111 edible insects globally, 255 species of insects are used as food by different tribes in India (Chakravorty 2014). In India, Coleopterans (34%) are the maximally consumed insects followed by Orthoptera (24%), Hemiptera (17%), Hymenoptera (10%), Odonata (8%), Lepidoptera (4%), Isoptera (2%), and Ephemeroptera (1%) (Chakravorty 2014). Insects are one of the important diets and consumed by various ethnic groups of northeastern states of India, especially among the tribes of Arunachal Pradesh, Assam, Manipur, and Nagaland and to a lesser extent by the tribes of Meghalaya and Mizoram (Shantibala et al. 2014). Sangma et al. (2016) recorded 158 species of insects consumed by ethnic people of

Arunachal Pradesh. In contrast, tribes of Nagaland consume only 42 species. About 81 species of regional insects are utilized in food and therapeutics by the Nyishi tribe of East Kameng and Galo tribe of West Siang in Arunachal Pradesh (Chakravorty et al. 2011). In the ethnic people of Kerala, Tamil Nadu, Madhya Pradesh, and Odisha, entomophagy is relatively much lower, consuming one to five insect species (Chakravorty 2014). A termite species, *Odontotermes formosanus* (Shiraki), is used as food to enhance lactation in women in Kanikaran and Palliyan tribes in South India (Wilsanand 2005).

13.10 Invasive Alien Insects

As per International Union for Conservation of Nature and Natural Resources, invasive alien species are exotic species which become established in natural or seminatural ecosystems or habitat and influence and threaten indigenous biological diversity. One-sixth of the global land surface is highly vulnerable to bio-invasion (Early et al. 2016). Invasive alien species are a severe threat to biodiversity, ecosystem services and functions, human livelihoods and health, and regional economy. They affect native species and communities through competition for resources, disease transmission, apparent competition, or pollination disruption (Kenis et al. 2009). National Biodiversity Authority's report on invasive alien species in India by Sandilyan et al. (2018) included 169 species of plants, microbes, fishes, insects, marine mollusks, invertebrates, amphibians, reptiles, birds, and mammals. Out of the total 68 animal species of IASs, 24 species (35.3%) were insects (Sandilyan et al. 2018). As of today, a total of 27 species of insects have been identified as invasive alien in India. The maximum number of invasive species is in Hemiptera (16), followed by Lepidoptera (5), Hymenoptera (3), and Coleoptera (3). A list of invasive alien species is given in Table 13.5.

13.11 Threats and Conservation

Habitat loss, deforestation and degradation, agriculture, the encroachment of forest land, grazing, human-wildlife conflict, forest fires, illegal extraction of forest products, commercial plantations, replacement of indigenous species with exotic species, and uncoordinated infrastructure development are among the major threats faced by biodiversity globally and in India (Wilson 1989; Chatterjee et al. 2006). Like other animal groups, insects have also been severely impacted because of habitat loss, invasive alien organisms, environmental contamination, and biological control (Samways 2006). As per estimates, insect biodiversity across the globe is declining

Table 13.5 List of invasive alien insects of India

S. N.	Order/name of the species	Family	Common name	Year
Hemiptera				
1.	*Eriosoma lanigerum* (Hausmann)	Aphididae	Woolly apple aphid	1889
2.	*Pterochloroides persicae* (Cholodkovsky)	Aphididae	Brown peach aphid	2018
3.	*Quadraspidiotus perniciosus* (Comstock)	Diaspididae	San Jose scale	1911
4.	*Insignorthezia insignis* (Browne) (=*Orthezia insignis* Browne)	Ortheziidae	Lantana bug	1915
5.	*Icerya purchasi* (Maskell)	Margarodidae	Cottony cushion scale	1921
6.	*Pineus pini* (Macquart)	Adelgidae	Pine woolly aphid	1970
7.	*Heteropsylla cubana* (Crawford)	Psyllidae	Subabul psyllid/leucaena psyllid	1988
8.	*Aleurodicus dispersus* (Russell)	Aleyrodidae	Spiraling whitefly	1993
9.	*Aleurodicus rugioperculatus* (Martin)	Aleyrodidae	Rugose spiraling whitefly	2016
10.	*Bemisia tabaci* (Gennadius) (=*Bemisia argentifolii* Bellows and Perring)	Aleyrodidae	Silver leaf whitefly	1999
11.	*Paracoccus marginatus* (Williams and Granara de Willink)	Pseudococcidae	Papaya mealy bug	2001
12.	*Phenacoccus solenopsis* (Tinsley)	Pseudococcidae	Cotton mealy bug	2005
13.	*Phenacoccus madeirensis* (Green)	Pseudococcidae	Madeira mealy bug	–
14.	*Pseudococcus jackbeardsleyi* (Gimpel and Miller)	Pseudococcidae	Banana mealy bug	–
15.	*Aleurothrixus floccosus* (Maskell)	Aleyrodidae	Woolly whitefly	2019
16.	*Aleurotrachelus atratus* (Hempel)	Aleyrodidae	Neotropical whitefly	2019
Lepidoptera				
17.	*Phthorimaea operculella* (Zeller)	Gelechiidae	Potato tuber moth	1937
18.	*Plutella xylostella* (Linnaeus)	Plutellidae	Diamondback moth	1914
19.	*Tuta absoluta* (Meyrick)	Gelechiidae	South American tomato leaf miner	2014
20.	*Spodoptera frugiperda* (Smith)	Noctuidae	Fall armyworm	2018
21.	*Citripestis eutraphera* (Meyrick)	Pyralidae	Snout moth/mango moth	–
Hymenoptera				
22.	*Leptocybe invasa* (Fisher and La Salle)	Eulophidae	Blue gum chalcid/ eucalyptus gall wasp	2006
23.	*Quadrastichus erythrinae* (Kim)	Eulophidae	Erythrina gall wasp	2005
24.	*Anoplolepis gracilipes* (Smith)	Formicidae	Yellow crazy ant	–
Coleoptera				
25.	*Hypothenemus hampei* (Ferrari)	Scolytidae	Coffee berry borer	1990
Diptera				
26.	*Liriomyza trifolii* (Burgess)	Agromyzidae	Serpentine leaf miner/American serpentine leaf miner	1990
27.	*Stenochironomus nelumbus* (Tokunaga)	Chironomidae	Lotus lily midge	2005

Source: Selvaraj et al. (2019), Chalapathi Rao et al. (2018), Sandilyan et al. (2018), Mathew and Habeeburrahman (2008), Bisht and Giri (2019), Singh et al. (2020), and Sundararaj et al. (2020)

dramatically, which may lead to the extinction of 40% of global species (Sánchez-Bayo and Wyckhuys 2019; Didham et al. 2020). Lepidoptera, Hymenoptera, and dung beetles (Coleoptera) appear to be the taxa most affected. Furthermore, four major aquatic orders, Odonata, Plecoptera, Trichoptera, and Ephemeroptera, have already lost a considerable proportion of species (Sánchez-Bayo and Wyckhuys 2019).

The IUCN Red List (August 2020) includes 22 species under the threatened category from India, distributed in Himalaya, Western Ghats, North-East India, and Andaman and Nicobar Islands (Tables 13.6 and 13.7). Eighteen species are Vulnerable, three species are Endangered, and only a single species is Critically Endangered (Table 13.6, IUCN 2020). The group-wise species list of threatened insects from India is given in Table 13.4. A total of 484 species of Indian insects are protected under Indian Wildlife (Protection) Act 1972, covering 444 species of butterflies, 38 beetles, 1 species of dragonfly, and one species of louse.

Thus global warming and climate change are making shifts in the diversity, geographic distribution, and abundance of insects. Long-term monitoring of insect population is required to identify the most affected regions and indications of a biological response to climate change. Zoological Survey of India has started a project to study the impact of climate change of lepidopterous insects in the Indian Himalayan region through long-term monitoring. Moreover, combined DNA sequencing and morphological characterization approaches can solve pest species complexes, therefore helping in the formulation of integrated pest management of crops. When analyzed in contrast with environmental parameters, the collection data present in the museums may also provide future distributional predictions of the pest species.

Table 13.6 Status of threatened insect species (Critically Endangered, Endangered, and Vulnerable) from the world, South and Southeast Asia, and India as per IUCN Red List (August 2020)

IUCN category	Global	South and Southeast Asia	India
Extinct	63	1	0
Extinct in wild	1	0	0
Critically endangered	336	31	1
Endangered	677	123	3
Vulnerable	806	150	18
Lower risk: Conservation dependent	3	0	0
Near threatened	594	121	19
Least concern	4752	888	307
Data deficient	2561	730	168
	9793	2044	516

Table 13.7 Checklist of threatened insects known from India as per IUCN Red List (August 2020)

S.N.	Order/name of species	Common name	IUCN category	Distribution
Phthiraptera				
1.	*Haematopinus oliveri* (Mishra and Singh)	Pygmy hog-sucking louse	Critically endangered	India (Assam)
Orthoptera				
2.	*Nicephora subulata* (Bolívar)	Palani Hills bush cricket	Vulnerable	India (Tamil Nadu)
Odonata (dragon and damselflies)				
3.	*Anisopleura vallei* (St. Quentin)	–	Vulnerable	India (Meghalaya, and Nagaland)
4.	*Bayadera hyalina* (Selys)	–	Vulnerable	India (Meghalaya); Thailand
5.	*Coeliccia fraseri* (Laidlaw)	–	Vulnerable	India (Meghalaya)
6.	*Disparoneura apicalis* (Fraser)	Black-tipped bambootail	Vulnerable	India (Kerala, Karnataka)
7.	*Indosticta deccanensis* (Laidlaw)	Saffron reedtail	Vulnerable	India (Kerala, Karnataka)
8.	*Libellago andamanensis* (Fraser)	Andaman heliodor	Vulnerable	India (Andaman Islands)
9.	*Libellago balus* (Hämäläinen)	–	Endangered	India (Nicobar Islands)
10.	*Protosticta sanguinostigma* (Fraser)	Red spot reedtail	Vulnerable	India (Tamil Nadu, Kerala, and Karnataka)
11.	*Chlorogomphus xanthoptera* (Fraser)	–	Vulnerable	India (Tamil Nadu, Kerala)
12.	*Chloropetalia selysi* (Fraser)	–	Vulnerable	India (Darjeeling); Nepal
13.	*Idionyx galeata* (Fraser)	–	Endangered	India (Tamil Nadu, Kerala, Karnataka)
Hymenoptera: Formicidae (ants)				
14.	*Monomorium effractor* (Bolton)	–	Vulnerable	India (Maharashtra)
15.	*Myrmica ereptrix* (Bolton)	–	Vulnerable	India (Jammu and Kashmir)
16.	*Pheidole lanuginosa* (Wilson)	–	Vulnerable	India (Arunachal Pradesh, Assam)
17.	*Pheidole parasitica* (Wilson)	–	Vulnerable	India (Arunachal Pradesh, Assam, Kerala)
18.	*Rhoptromyrmex mayri* (Forel)	–	Vulnerable	India (Maharashtra)
Lepidoptera (butterflies)				
19.	*Bhutanitis ludlowi* (Gabriel)	Mystical Bhutan glory	Endangered	India (Arunachal Pradesh); Bhutan
20.	*Euploea andamanensis* (Atkinson)	Andaman crow	Vulnerable	India (Nicobar Island and Andaman Island); Myanmar
21.	*Euploea scherzeri* (Felder)	Cinnamon crow	Vulnerable	India (Nicobar Island and Andaman Island)
22.	*Graphium epaminondas* (Oberthür)	Andaman swordtail	Vulnerable	India (Nicobar Island and Andaman Island)

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Chapter 14
Status, Issues, and Challenges of Biodiversity: Forest Insects

O. K. Remadevi

14.1 Introduction

14.1.1 Forestry Resources and Their Economic Importance

India's forest ecosystems support the economy and livelihood of approximately 300 million tribal and local people in forest villages. Covering 80.73 mha or 24.56% of the geographical area of the country, forests are home to 80% of the terrestrial biodiversity, provide 40% of energy needs, and 30% of the fodder supply (Roy 2020). The natural renewable resources fulfill the necessities of the society and provide vital ecosystem services, such as combating desertification, protecting watersheds, maintaining biodiversity, enhancing carbon sequestration, and playing an important role in protecting the environment necessary for life and human health. Forests offer a great deal of economic benefits to people and communities, and forest products including wood and other minor forest products such as food products, fibers, rubber, gums, resins, waxes, tannins, pharmaceuticals, cosmetics, and many other speciality products also have a substantial contribution toward the economy of India. Non-wood forest products (NWFP) play a very important role in the modern economy. Forestry in India plays a significant role in preserving the ecological balance of natural ecosystems. It supports small-scale village forestry or agroforestry to huge plantations, be it commercial timber species, NWFP species, or short-rotation forestry crops for paper and pulp, plywood or medicinal plants, and oil-yielding species or fodder crops. Forests provide food, timber, fuelwood, fiber, and non-wood forest products (NWFPs), including medicinal plants, small timber,

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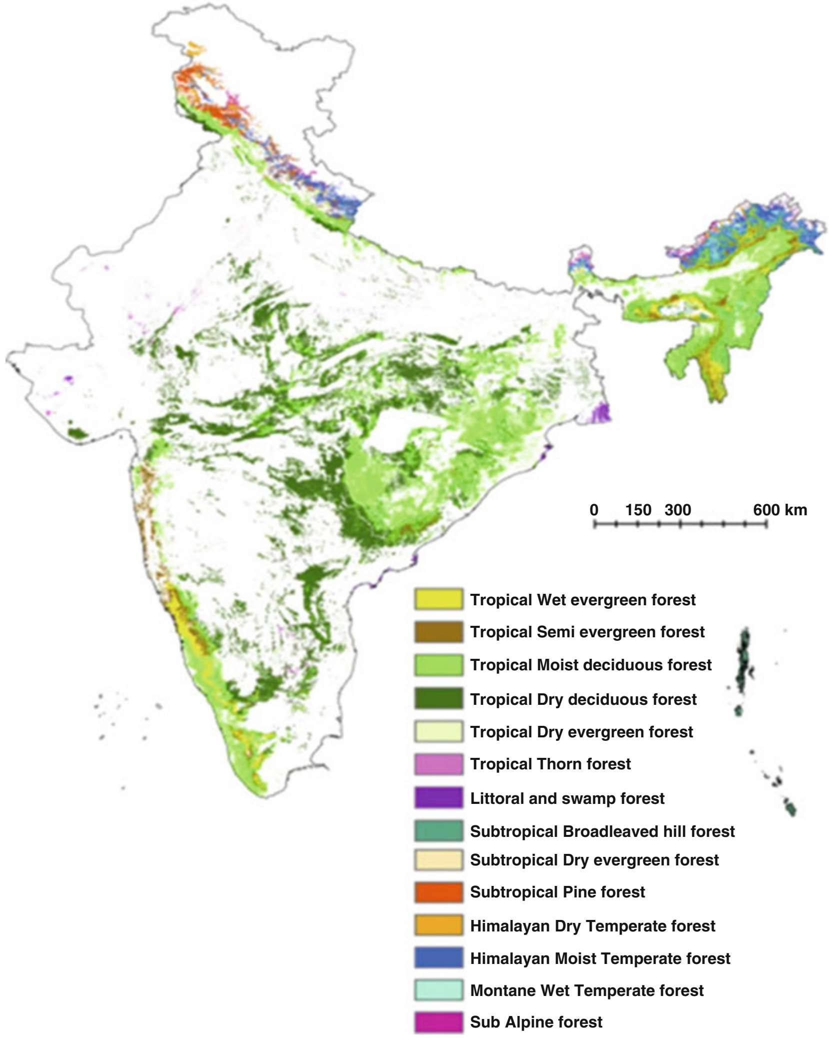


Fig. 14.1 Forest type map, India (ISRO)

and raw materials catering to the needs of various wood-based industries. Nearly 350 million people living in and around forests in India depend on forests for their sustenance and supplemental income. For landless families and marginal farmers, forest-related activities often represent the primary source of income. Many landless people depend on daily wages related to the collection of NWFPs.

The forest classification system of India (Champion and Seth 1968) includes 14 forest types. Figure 14.1 shows the distribution of forest types prepared by the Forest Survey of India. Biological invasions, leading to radical alterations to the functioning of ecosystems, have happened for years. Acacia species that are commercially important have been extensively planted in areas outside their natural range. Eucalypts have had modest invasive success in many areas. The Indian forests have also been subject to extensive use and modification by unsustainable exploitation, and illegal logging. Tropical dry deciduous forests are found in severe and extremely variable climates characterized by low rainfall and nutrient-poor soils, where woody plants possess several functional traits that permit them to endure severe water stress for several months of the year. Canopy trees on drying soils typically respond to an extended drought by shedding their leaves. The lack of precipitation during several months of the year produces ecosystems that have adapted to survive a prolonged dry season. Deciduousness is the single most important adaptation among plants to extended droughts. According to Singh and Chaturvedi (2017a, b), these forests are among the most vulnerable and fragmented ecosystems in the world. In India, tropical dry deciduous forests are widely distributed over a large area. Over the past two decades, India has witnessed an ever-increasing rate of deforestation and unsustainable exploitation of forest resources, leading to overall degradation at an alarming rate.

Depending on the ecoclimatic and edaphic factors in the forest types, the biodiversity of trees differs greatly in the different forest types. As the majority of insects are herbivores, some of which are monophagous, the insect diversity is also accordingly altered. Specific studies on insect fauna in different types have been conducted and documented. However, the faunal composition varied with the floral distribution and intensity.

In its pledge to reduce the emission intensity of its GDP by 33–35% by 2030 (from 2005 levels) through mitigation efforts across various sectors, India envisions creating an additional carbon sink of 2.5–3.0 billion tons (Bt) of CO_2 eq through additional forest and tree cover by 2030 as per its NDC targets. India is now ranked third in the world for an annual net gain in terms of forest area. The biennial India State of Forest Report 2019 released by the Union Ministry for Environment, Forest and Climate Change reports that India has achieved an increase of 24.56% in its total forest and tree cover.

Most of the forest ecosystems of India are fragile and reeling under acute pressure of degradation. Since 78% of the forest area is subjected to grazing, coupled with heavy removal of forest products and 51% subjected to occasional fire, the productivity of Indian forests has fallen very low. In India, forests meet nearly 40% of the energy needs of the country, of which more than 80% is utilized in the rural areas and about 30% of the fodder needs of the cattle population. Of the total wood requirement, 70% is for fuel wood and 30% for timber. The forests in India face at least five times more stress than they can endure. Also, 178 million tons of green fodder and 145 million tons of dry fodder that contributes to about 30% of the fodder requirement of the country, are obtained from forests. Out of the 30 million m^3 timber requirement, 8.3 million m^3 is required for paper, pulp, and panel products, and 15.4 million m^3 is utilized for saw milling, i.e., housing, packaging, furniture, etc. (Singhal et al. 2003).

India is blessed with a variety of timber-yielding tree species, and as many as 1500 species are commercially utilized for diverse purposes. Some of the important plantation tree species grown in India are *Tectona grandis*, *Eucalyptus* spp., *Acacia* spp., and *Dalbergia sissoo*. Productivity of forests in general, and particularly that of commercial forest plantations, is very much affected by frequent outbreaks of pests and diseases, besides human interventions and various natural calamities. The dense forests in almost all the major states have been reduced, and forest degradation is a matter of serious concern now. Principal plantation species such as *Acacia* spp., *Eucalyptus* spp., and *Tectona grandis* Linn. Are the main species occupying a greater area in planted forests. The other species such as *Swietenia* sp., *Santalum album*, *Melia dubia*, *Ailanthus excelsa*, *Leucaena leucocephala*, *Eucalyptus globules* Labill., *E. grandis* W. Hill ex Maiden, *E. tereticornis* Sm., *Acacia auriculiformis* A. Cunn. ex Benth., *A. catechu* (L.) Wild. Oliv., *Albizia* spp., *Azadirachta indica* (L.) Adelb., *Casuarina equisetifolia* L., *Dalbergia sissoo* Roxb., *Gmelina arborea* Roxb., *Populus* spp., *Prosopis* spp., *Shorea robusta* Roth, *Terminalia* spp., *Cedrus deodara* (Roxb.) G. Don, and *Pinus roxburghii* Sargent are also planted for various commercial utilization purposes.

Commercial forestry is an important industry in India, with about 17 million hectares under forest plantation. Pest management in plantations, where productivity is often affected by the outbreak of pests and diseases, has always been a challenge for the forest development agencies and planters in India. Productivity decline in plantations is well demonstrated in one of the examples of a long-term study on teak in India by Nair et al. (1996), where the authors reported an estimated loss of about 44% of the potential volume increment in 4–9-year-old trees due to attack by a serious defoliator pest, *Hyblaea puera* Cramer. This loss is substantial, and the defoliator attack affects the quality of the timber from one of the most versatile timber-yielding species in our country. Similar insect infestations are known to affect many other highly valued species of timber-yielding trees, often jeopardizing the economic viability of commercial forestry.

14.1.2 Forest Insects

Insects, in general, are ubiquitously found on land, in water, and in the air in almost all habitats and in different continents including Antarctica, richest being in tropical belts. They are very closely related to the environment, vegetation cover, and overall climate and are sensitive to habitat disturbances. A fast reproductive cycle and a large number of ecological interactions, as well as easy visibility and inexpensive collection, make them the best bio-indicators in the forest ecosystem. Understanding insect diversity in the humid tropics is one of the major challenges in modern ecology. Some information sources estimate that tropical forest in the Amazon basin forms a habitat for more than 30% of insect species globally; however, insects also play a significant role in agro-ecosystems and other cultivated habitats outside forests and have not yet been thoroughly studied.

Tropical, temperate, and boreal forests offer a diverse set of habitats for plants, animals, and microorganisms. Consequently, forests hold the majority of the world's terrestrial species. Forests covering all types of habitats with the highest diversity of plants hold the maximum diversity of insects, occupying diverse niches and trophic levels. They exhibit diverse morphological characteristics occupying many Insect taxa, performing a multitude of functions with both beneficial and harmful effects and many with neutral ecological functions.

With over half of the world's insect species believed to be endemic to tropical forests, a good chunk of which is destined for degradation before the end of the century, the number of extinctions may exceed our "worst nightmare" (Collins 1987). Insects have an important role to play in conservation assessments because of their dominance in terrestrial ecosystems (Wilson 1987), their short generation times that can result in rapid population response to disturbance, and their wide range of lifestyles that make them sensitive to changes in the biotic and abiotic environments (Kremen 1994).

Understanding the extent and causes of insect diversity in the humid tropics is one of the major challenges in modern ecology. Although the true figure is now widely thought to be between five and ten million species, recent calculations presume that there may be more than 30 million species of insect on earth. Beeson (1941) published a handbook that included details on 4300 insects associated with forests in the Indian region. Pests of forest trees and timber, beneficial insects, and those that attack man and animals are included. At least one representative of every combination of insect, plant, and locality known to occur in Indian forests is covered. The book covers a short preliminary survey of the history of forest entomology in the Indian region. A section by J. C. M. Gardner on the development of systematic entomology is also incorporated in this book. The remainder of the chapter is divided into two parts, of which the first deals with the ecology of forest insects and the second with their control. The first part comprises information on individual species, with details on food plants, account of the bionomics, the nature and extent of the injury caused, and the economic importance. Descriptive notes and distinguishing characters are also given. Characteristics of the various insect orders and families, feeding habits of insects, identification and the economic loss due to insect pests in forests are also discussed. The second part is devoted to a general account of silvicultural, biological, mechanical, and chemical control. One section deals with the control of the noxious weeds, *Opuntia* and *Lantana* by insects. A discussion of the relative importance of insects, fungi, viruses, and growth conditions in the dying-off and die-back of the more important timber trees, along with control measures for specific pests, are dealt. Brief notes are included on the collection and transport of living and dead insect material. Hence this book forms an ideal reading material for anyone interested in forest insects. However, this number is not indicative of the real number of Indian forest insects, which is yet a topic of investigation.

14.1.3 Insect–Plant Relationships

Insect-plant relationship in forests may be beneficial or detrimental, influencing the germination, growth, and survival of plants. Certain groups of insects cause severe damage to different plant parts, sometimes leading to plant death. These harmful insect groups include folivores (leaf eaters), florivores (feeding on floral parts), frugivores (fruit eaters), and xylophages (wood feeders). Among the pests, largely insects belonging to the orders Coleoptera, Lepidoptera, Isoptera, and Homoptera are the major ones of significant economic importance that attack trees, right from the seeds to the final product. Wood deterioration by xylophagous insects leads to unhealthy tree growth and malformation of wood in timber yielding forest trees. Some such major pests belong to Lepidoptera, Coleoptera, and Isoptera. Insects that are beneficial to plant life include predators and parasites of herbivores and pollinators. Predatory insects feed on herbivorous insects that are detrimental to plant growth. Parasites, which comprise mainly hymenopterans and dipterans, lay eggs and develop on herbivorous insects and play a beneficial role in the growth and survival of plants. Pollination is an important ecosystem service rendered by insects that helps plants in reproduction.

14.2 Diversity of Forest Insects

14.2.1 Forest Insect Pests

Productivity of forests in general, and particularly that of commercial forest plantations, is very much affected by a frequent outbreak of pests and diseases, besides by human intervention and various natural calamities. Other than natural forests, insect pests attack the forest nurseries and plantations too. While they are integral components of forest ecosystems, insects and diseases have considerable influence on the health of forests, trees outside forests, and other wooded lands as they have significant economic and social impacts on forest productivity and values. Most of the insect species are minor pests and sometimes assume the status of key pests as they have the potential to multiply in amazing numbers due to their high reproductive rate and short life cycle. In general, more information is available on pests of trees grown in commercially valuable planted forests (which include plantation forests and planted semi-natural forests) compared to pests in naturally regenerated forests. Virtually nothing is known of the pests associated with those trees in naturally regenerated forests, at least in the tropics. The monoculture plantations are much more susceptible to insect epidemics as compared to mixed plantations.

Hundreds of insects are known to damage both naturally regenerating forests and plantations in India; fortunately, only a few of them are pests and even fewer are chronic and common and cause severe enough damage to warrant preventative or remedial action. The growth and productivity of forests are adversely affected by frequent outbreaks of pests and diseases. About 20% of the entire negative growth impact on forest trees is caused by forest insects. Several groups of insects belonging to orders Coleoptera, Hymenoptera, Lepidoptera, and Isoptera are the major pests that cause high economic loss. The most commonly reported pest species belong to the orders Coleoptera and Lepidoptera, which together make up over 70% of all insect pest species reported. Hemipteran species are the third most important insect order at 16%. The damage to nursery stock by forest insects is often considerable at times. The most important among the nursery pests are cutworms, termites, and cockchafers besides some defoliators, sapsuckers, and shoot borers as major pests. Natural and plantation forest trees in India suffer serious seasonal insect outbreaks, which lead to considerable economic loss in timber productivity.

When some insects threaten the overall health of the trees or compete with us in the use of the forest and attack valuable trees, killing or weakening them so that other insects or diseases can attack, they are considered and identified as pests. Some pests can target many tree species, while some affect a few species or just a given tree species of a certain age in a forest. They play a decisive role in determining the efficiency in the production of merchantable wood and other associated biological and chemical products. Insects occur throughout all life stages of the forest. Some pests attack seedlings, others affect the sapling stage, usually before crown closure, while others attack mature or over-mature trees. Young or mature/over mature trees are the most vulnerable to forest pests. Among insects destructive to hardwoods, there are defoliators, root-feeding insects, bark feeders, and bark borers, wood borers, sucking insects, seed-destroying insects, canker formers, gall formers, sap destroying insects, etc. Insects can negatively impact forests in several ways. Forest pests can slow down tree growth and yield, affect the survival of the tree below an economic threshold, reduce the quality of wood and non-wood products, cause dieback, decline, and deformity, and reduce biological diversity. The impact of a pest attack is usually measured in relation to the number of trees killed, the volume of timber lost, the areas of defoliation, or the amount of growth loss.

Many researchers have studied the insect fauna in diverse forest ecosystems (Nair 2007). Stebbing (1914) was the first to record an insect pest of mangroves from anywhere in India. He reported that *Diapus neritierae* Stebbing (*Crossotarsus externedentatus)* (Coleoptera: Platypodidae) bores into both the green and half dry wood of *Heritiera littoralis*. Veena Kumari et al. (1997) reported 197 species of insect herbivores, 43 species of parasitoids, and 36 species of predators from mangroves of Andaman and Nicobar islands. Raji and Remadevi (2004, 2005) conducted a detailed study of entomofaunal diversity along the west coast of India. Entomofauna of mangrove ecosystem of India – an annotated checklist is published (Remadevi et al. 2008).

14.2.1.1 Defoliating Insects

Defoliation is the removal of all or part of the foliage from the tree. Insects are the primary agents that can cause defoliation. Insect defoliation is one of the serious problems encountered in plantations and forests. Such insect infestations frequently affect the quality and quantity of timber yield from trees, jeopardizing the economic viability of commercial forestry. In spite of the efforts to understand and manage this problem, it still exists as a severe problem requiring to be addressed. The severity of defoliation varies from place to place and time to time. Insect species belonging to the orders Lepidoptera, Hymenoptera, Coleoptera, Orthoptera, and Diptera cause the majority of defoliation on forest trees. These groups include many species of caterpillars, sawflies, beetles, walking sticks, and miners. *Hyblaea puera* Cramer, *Paliga machoeralis* Walker, *Clostera* spp., *Heliothis* spp., *Lymantria* spp., etc. in the order Lepidoptera and *Anomala* spp., *Holotrichia* spp., *Apoderus* spp., *Adoretus* spp., etc. belonging to Coleoptera are common species causing defoliation. Some of the major foliage feeders that cause considerable damage in the forest ecosystem of south India are *H. puera*, *P. machoeralis*, *Sahyadrassus malabaricus*, *Hypsipyla robusta*, *Atteva fabriciella*, *Eligma narcissus*, *Dasychra mendosa*, etc. Leaf herbivory in three species of *Avicennia* in Coringa mangroves of the east coast was quantified and compared (Chatterjee et al. 2019).

Forest nurseries attract many insects

Defoliators harm trees by feeding on leaves, weakening trees by reducing their sugar/starch-producing capacity, interfering with transpiration and translocation within the tree, and reducing photosynthesis. The impact of defoliation on individual trees is dependent on a variety of factors. The extent of damage to a tree or forest depends on the number of leaves eaten, time of the attack, tree species, health, and single or repeated defoliation. While the loss of leaves slows the growth of the tree, hardwoods can generally survive a few consecutive years of defoliation, although they will be stressed. The trees stressed from defoliation, drought, or other disturbances may die 1–3 years later due to the general weakening of the plants and repeated attacks.

Defoliators of Some Major Tree Species

Ailanthus: Some of the important species that occur in India are *Ailanthus excelsa* Roxb and *A. triphysa* (Dennstaedt), suitable for introduction in social forestry, agroforestry, avenue plantation, industrial plantation, and wasteland afforestation. Bhasin and Roonwal (1954) reported 17 insects associated with *Ailanthus* belonging to five orders as Coleoptera, Lepidoptera, Hemiptera, Thysanoptera, and Isoptera. Five more new insects were recorded by Varma (1982) on *A. triphysa.* Among the various pests, the defoliators, *Atteva fabriciella* Swederus and *Eligma narcissus*

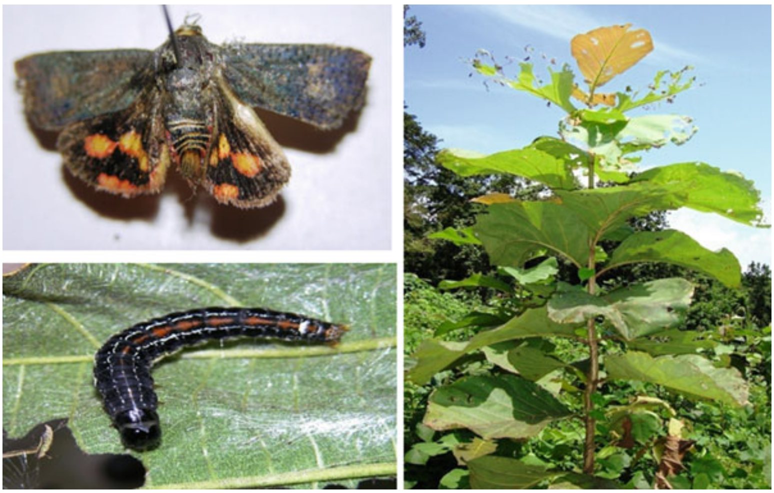
Rothschild are the major ones, particularly in South India. Repeated defoliation causes a serious setback to the growth of trees, which are so weakened that they become easy prey to the attack of other pests. This insect is commonly known as *Ailanthus* webworm because of the larval habit of webbing the leaves together and feeding on within. The number of larvae at a time in a web may vary from 6 to 10. It is reported around the year, signifying continuous breeding with overlapping generations (Varma 1986). The pre-monsoon period shows a decrease in population that subsequently reaches a high level in the monsoon period. The intensity of attack decreases in the summer months, and infestation continues with the onset of rain.

Eligma narcissus infestation in *Ailanthus excelsa*

As a result of repeated defoliation, the young plants are badly weakened or killed completely, and the growth of mature trees is severely retarded, leaders and laterals die back, seed formation is drastically reduced, and tender fruits are damaged *E. narcissus* is recognized as a serious pest of *Ailanthus* in Southern India. It is distributed all over India and feeds on *A. excelsa*, *A. triphysa*, and *A. grandis*. Pest buildup is generally on the increase during September–January (Varma 1986). About 20–40 larvae feed voraciously on each leaf at times of heavy defoliation. Usually, saplings up to 5 years old are infected, and mature trees are free from attack although the reason for this trend is not known. Defoliation of *Ailanthus* by this pest causes apparent loss of growth increment. Larvae are reported to feed on green parts of the stem when all the leaves are consumed. Pest incidence in older plantations is rare compared to young plantations.

Teak (*Tectona grandis* Linn. f.) (Family: Verbenaceae) known as the king of timber is a potential and most valuable timber tree species in India. It is one of the most well-known and favoured timbers in the world. It is a large deciduous tree that occurs mainly in a mixture with other hardwood timbers in the mixed moist and dry deciduous forests of Western Ghats. Insect damage is a serious problem in teak plantations. More than 187 insect species have been found feeding on teak trees in India. A majority of these insects are defoliators, with a smaller number of sap feeders, stem borers, inflorescence, and fruit feeders and root feeders. Most insect defoliators belong to the order Lepidoptera, whose larval stages feed on leaves. Defoliator insects cause severe defoliation and hence reduce growth rate, apical dominance, and the seed production capacity of plantations and seed orchards. These insects generally have very high reproductive potentials and short life cycles. Hence, rapid population buildups can be expected within a very short period of the establishment of the insect pests. The most important lepidopteran defoliators that cause epidemic defoliation in teak plantations throughout the tropics are the teak defoliator, *Hyblaea puera* Cramer (Hyblaeidae) and teak skeletonizer, *Paliga machoeralis* Walker (Pyralidae) (Tewari 1992). Outbreaks of these insects may occur two or three times during the growing season (Chandrasekhar et al. 2005).

Paliga machoeralis moth; teak leaves infested by *P. machoeralis*



Hyblaea puera moth and larva; teak leaves infested by *H. puera*

The damage by the defoliators *H. puera* and *P. machoeralis* adversely affects the tree growth and vigor besides causing certain abnormalities resulting in loss of timber quality. Of the two, *H. puera* is more serious than *P. machoeralis* because it feeds on young leaves during the early part of the growing season while the latter feeds on older leaves. Among leaf feeders, the teak defoliator *H. puera* is the most widespread and serious pest in both plantation and natural forests, with 14 generations per year (Beeson 1941). Defoliation by *H. puera* in 4- to 9-year-old plantations was reported to cause 44.1% volume increment loss (Nair et al. 1996). They directly retard girth increment, loss of timber quality by forking, death of the leading shoot, and formation of epicormic branches. After outbreaks, the plantation growth rate may be reduced by as much as 75%. Evidence gathered from the past decade on the population dynamics of *H. puera* indicates habitual, short-range movements of emerging moth populations, suggesting that these spread to larger areas, generation after generation, affecting entire teak plantations (Chandrasekhar et al. 2005). Generally, mature caterpillars descend to the ground on silk threads and pupate in the soil. In rainy months, pupation occurs in the leaves of ground vegetation.

The teak skeletonizer *P. machoeralis* is the most pernicious oligophagous pest of teak responsible for epidemic defoliation regularly in nurseries, plantations, and natural forests throughout South Asia and some parts of Southeast Asia (Kulkarni et al. 2011). Outbreaks of this species occur in most years, with an exceptionally heavy buildup in some years. Although the insect is present throughout the year, outbreaks develop toward the end of the growing season. Complete defoliation by the pest results in more or less leaflessness during most of the growing period. Damage varies from almost negligible to as much as half of the total annual increment. It causes losses amounting to 65% in plantations along with *H. puera* and 54.77% in seedlings in nurseries. Loss in volume increment ranging from 8.3 to 65% was reported due to three consecutive defoliation outbreaks of *P. machoeralis* within one growing season in India (Tewari 1992).

The Bihar hairy caterpillar *S. obliqua* (Lepidoptera: Arctiidae) recorded feeding on as many as 33 host plants including many agricultural and garden plants and also on numerous species of forest shrubs and trees including *Tectona grandis*, *Butea frontosa*, *Cedrela toona*, *Colebrookia oppositifolia*, *Lantana camara*, *Morus alba*, *Morus indica*, and *Vitex negundo*. The pest makes its first appearance from its winter hibernation in March. It occurs almost throughout the year, and infestation is severe from August to December and also sometimes in January. There are six generations of this pest in a year, indicating the potential of this pest to cause severe defoliation of the host plants. Young caterpillars are gregarious, and they feed on the green soft tissues of tender leaves, mostly on the under the surface of the leaves, leaving behind only the veins. Grown-up caterpillars are solitary and feed voraciously on entire leaves, causing defoliation of the plants leading to a significant reduction in yield. Destroying one field, they move in swarms to another field.

14.2.1.2 Xylophagous Insects

While the folivorous pests reduce the leaf biomass and lead to impaired growth of trees, the wood-feeding pests cause the malformation of stem and final timber structure and also reduce the timber yield. The borer *Xystrocera festiva* Pasc. and *Zeuzera coffeae* Nietner affect the agro-forestry plantations and saplings of *A. mangium* Willd. and *Eucalyptus* spp., which decreases the quantity and quality of timber. The borer *X. festiva* has several hosts including *Paraserianthes falcataria* (L.), *Pithecellobium* sp., *Albizia saman* F. Muell., and *Enterolobium* sp. The estimated yield loss in young trees (4 years old) was about 12% and about 74% in mature trees.

The tusam pitch moth *Dioryctria rubella* Hampson bores in the young shoots (up to 30 cm) of *Pinus merkusii* Jungh. & de Vriese (Tusam) causes dieback of the shoots and stem. The ambrosia beetle *Xyleborus destruens* Bldf. and the bee hole borer *Xyleutes ceramica* Walker attack the trunk of teak trees and make branching tunnels that extend into the heartwood. The 3-year-old trees of *T. grandis* were infested by the wood-dwelling termite *Neotermes tectonae* Damm., where the portion of stem and branches were hollowed.

The larvae of *Indarbela quadrinotata* Walker bore into the shoot of *Santalum album* L. and form a shelter tunnel downward in the wood from which it emerges to feed upon the outer surface of bark at night. *Aristobia octofasciculata* Aurivillus is also reported to bore into the heart wood of this tree (Beeson 1941; Remadevi and Rajamuthukrishnan 1998, 2007). The volume of wood lost due to the attack of insects and microbes in the two most important trees *S. album* and *T. grandis* has been estimated (Remadevi and Veeranna 2005). *Toona sureni* (Blume) is mostly planted as an individual in private lands, often mixed with other plant species, and it is a native host of *Hypsipyla robusta* Moore. The insect attacks flowers and young fruits of *T. sureni* and mahogany. The growing shoot is mostly preferred and is the most serious pest of mahogany now.

Termites and Their Impact

Termites are an important part of the community of decomposers. They are able to decompose cellulose, the main component of the wood. They are abundant in tropical and subtropical environments. These termites become economically important pests when they start destroying wood and wooden products of human homes, building materials, forests, and other commercial products. There are over 2800 described species of termites, with about 185 considered pests (Lewis 1997). Termites that belong to the families Hodotermitidae (*Anacanthotermes* and *Hodotermes*), Kalotermitidae (*Neotermes*), Rhinotermitidae (*Coptotermes*, *Heterotermes*, and Psammotermes), and Termitidae (*Amitermes*, *Ancistrotermes*, *Cornitermes*, *Macrotermes*, *Microtermes*, *Microcerotermes*, *Odontotermes*, *Procornitermes*, and *Syntermes)* cause great loss in natural and plantation forestry.

In India, they are responsible for 15–25% of crop loss, which amounts to huge losses annually. The major mound-building termite species in India are *Odontotermes obesus* Rambur, *O. redemanni* Wasmann, and *O. wallonesis* Wasmann. The subterranean termite species *Heterotermes indicola* Wasmann, *Coptotermes kishori* Roonwal & Chhotani, *C. heimi* Wasmann, *O. horni* Wasmann, *Microtermes obesi* Holmgren, *Trinervitermes biformis* Wasmann, and *Microcerotermes beesoni* Snyder attack the bark and heartwood of the standing trees such as *A. leucophloea*, *Butea monosperma* (Lam.) Taub., *Dipterocarpus indicus* Bedd., *Eucalyptus* sp., *Pterocarpus marsurpium* Roxburgh, *Santalum album*, *Shorea robusta*, *Terminalia bellirica* (Gaertn.) Roxb., *Swietenia macrophylla*, *Dalbergia sissoo*, *Pinus wallichiana* A. B. Jacks., *T. grandis*, *Toona cilita*, and *Haldina cordifolia* (Roxb.) Ridsdaleetc. *Odontotermes* spp. are the major arboreal termites damaging the bark and stems of many species of trees, including sandalwood and teak, and chemical methods of management have been tested (Remadevi et al. 1998).

14.2.1.3 Timber Beetles

The most serious pests of timber are wood-boring beetles of the order Coleoptera, which is the largest group in the animal kingdom, containing nearly one-quarter of a million known species, which is equivalent to about 40% of the insects. Beetles consume wood from the inside after boring into it. Generally, they can be detected by the presence of frass outside the timber. Wood feeding beetles generally fall into two major groups: large borers belonging to the families Cerambycidae and Buprestidae and small borers belonging to the families Bostrychidae, Platypodidae, Scolytidae, Lyctidae, Curculionidae, and Anthribidae. Usually, different groups of beetles attack timber in succession, at various stages from freshly felled to dry-processed material. The first group to attack is usually Buprestidae, Cerambycidae, Platypodidae, Scolytidae, and Curculionidae, and later on by the insects of the families Bostrychidae and Lyctidae. Some of these families may sometimes occur together. The decisive factor appears to be the moisture content of the wood. The mango borer *Batocera rufomaculata* and the cashew borer *Plocaederus ferrugineus* on live wood of trees and furniture beetles *Anobium punctatum* (Anobiidae), *Lyctus africanus* (Lyctidae), and *Sinoxylon anale* (Bostrychidae) are examples of certain wood-inhabiting beetles of economic importance. A great number of beetles exist, specializing in the deterioration of timber in its various forms. Dry wood insects preferably attack wood below fiber saturation. Like termites, they are also able to live in seasoned or dry wood, in contrast to all other wood attacking organisms. This makes them especially dangerous to all kinds of wood constructions out of contact with the ground, even when protected against weathering.

The main groups of wood-destroying beetles are pinhole borers or ambrosia beetles (Scolytidae and Platypodidae) that attack greenwood, powder-post beetles (Lyctidae and Bostrychidae) that attack seasoned or dry wood, long-horned beetles or round-headed borers (Cerambycidae), and a few jewel beetles or flat-headed borers (Buprestidae). The last two families include the xylophagous species, which damage weak trees or logs with bark. Wood-boring beetles that derive their nutrients from carbohydrates must ingest relatively large quantities of wood in order to extract sufficient digestible substances for their growth. The female beetle is able to detect the suitability of timbers for oviposition in relation to its food value for larvae. It will thrive in a wood with a moisture content between 10 and 50%, the higher moisture content being more favourable. Wood with less than 10% moisture content is not attacked (Beeson 1941), and starch content of 1–1.5% is considered to be the minimum for Lyctids. The bamboo borer requires a much higher starch content of 10–15%.

Pioneering studies on the timber beetles found in the Indian sub-continent were made by Stebbing (1914) during the turn of this century. He gave a detailed account of the morphology, taxonomy, biology, and bionomics of various species attacking important timbers. Later Beeson (1941) summarized subsequent works on timber beetles, including the biology of some important borers. The borer fauna of temperate and tropical zones of India has been investigated by several workers (Beeson 1941; Thakur 1988; Sarasija et al. 2012).

Gnanaharan et al. (1985) studied timber beetles associated with commercially important stored timber in Kerala and their control. A list of 38 species of insect pests of rubberwood in India, belonging to the families Cerambycidae, Platypodidae, Curculionidae, and Bostrychidae, is given by Mathew (1990). There are many insects that attack standing trees and which may continue to attack the log after felling. Some of these may continue to live in wood during drying. A brief account of these insect pests is given below.

Pin Hole Borers or Ambrosia Beetles

There are two distinct types of Ambrosia beetles, namely the bark beetles (Scolytidae) and the heartwood borers (Platypodidae). The adults of both families are between 1 and 12 mm long, slender, and often of black or brownish in colouration. The adults tunnel radially into the heartwood of the host and create a system of galleries in which eggs are laid. The types of galleries made by the parents are species-specific. The larvae do not feed on wood but live on a fungus that they cultivate on the gallery walls. The Ambrosia fungus smells a bit like beer, and therefore the beetles are also called Ambrosia beetles. The scent acts as an allelochemical that attracts even more bark beetles to the infested tree. Once the larvae are fully grown, they pupate inside the galleries. The newly hatched adult beetles leave the system of galleries through the entrance hole made by their parents and fly off for mating. The life cycle takes about 14 weeks for larger species and 3–4 weeks for smaller species. An infestation with ambrosia beetles can occur either in the natural forest, in plantations, or in the log yard. The attack can start within a few hours of the felling of a tree, increase during the next few days, and can last for many weeks. The rate of infestation depends on the type of wood and the moisture content of the wood. Usually light, white wood is more susceptible than heavier, red or brown wood. As long as the tree is green and contains a lot of sap, it can be easily attacked. Once the moisture content decreases below 50%, the timber is unlikely to be infested. Wet climatic conditions or rafting of logs also support the attack since the wood cannot dry properly. The beetles feeding on green timber attack only where sapwood is present but can penetrate the hardwood, too. In log yards, a few different species of pin and shot hole borers attack areas of the log where the bark has been removed. The attack of sawn timber is unusual as long as the moisture content of the lumber is low. Live trees in plantations and natural stands are attacked if the trees suffer from stress. Several stress factors, like an infestation with other pests, contribute toward an ambrosia beetle attack. Damaged trees injured during commercial thinning or by fire as well as trees stressed by drought are far more susceptible to an infestation. The "pin hole" describes the appearance of timber attacked by the beetles, showing on the surface a large number of small holes in which needles can easily be introduced.

Pin hole borer tunnels are characteristically clean and free from bore dust, which distinguishes them from other beetles. The tunnels show darkly stained edges, and streaks of stained wood can be observed extending for some distance from the holes along the grain. This discolouration results from the reaction of the living wood cells to the invading air and affects the timber quality much more than the holes themselves, though the strength of the timber is not significantly reduced. The light hard woods are commonly very sensitive and can suffer attacks of even more than one thousand entrance holes per square decimeter of log surface. Certain species of

Xyleborus and *Platypus* are most dangerous to peeler logs, where even the smallest holes and discolouration cause a loss in valuable veneer.

Longhorn Beetles (Cerambycidae)

The **longhorn beetles** (**Cerambycidae**; also known as **long-horned beetles** or **longicorns**) are a cosmopolitan family of beetles, typically characterized by extremely long antennae, which are often as long as or longer than the beetle's body. The family is large, with over 35,000 species described, belonging to some 4000 genera classified under 11 sub families, slightly more than half from the Eastern Hemisphere. Several are serious pests, with the larvae boring into wood, where they can cause extensive damage to either living trees or untreated lumber (or, occasionally, to wood in buildings). Where the heartwood is infested, veneer and timber produced from the logs bear evidence of the damage. Often large cavities are exposed when the log is converted to timber.

The female deposits the eggs in or under the bark. The grubs bore into the bark or at the bark–sapwood interface. They pack their tunnels with excreta and coarse wood fibers behind them. Only the mature larva penetrates into the sapwood or heartwood to pupate, normally forming a tunnel like a "U" shaped tube, with its blind, closed end near the outer surface of the wood. As the diameter of the meandering tunnels corresponds with the diameter of the larva and may reach up to 3 cm, the destruction is considerably high. Finally, the adult insect leaves the wood making an elliptical hole on the surface, sometimes more than 1 cm in diameter. The majority of long horn beetles infest all kinds of barked hardwoods with sufficient moisture content.

Insects Associated with Partially Dried Timber

Two important families of beetles (belonging to Bostrychidae and Lyctidae) attacking recently dried or partially dried timber are grouped together under the name "powderpost." The popular name relates to the fine powdery frass that is produced by the larvae.

Powderpost Beetles

Powderpost beetles attack and destroy hardwood that has at least moderate starch content. Their attack is confined to the sapwood of pored timbers, whereas conifers are generally not susceptible. The consequences of infestation are summarized by the term "powderpost." Wood, when heavily attacked, is reduced to fine powder by the adults and immature beetles. They leave the outer layer of the wood intact while destroying all within. Bostrychids are generally highly polyphagous. The presence of starch is believed to make the wood attractive to them. Debarking increases the damage by exposing the sap wood. Some timbers like rubber wood are highly susceptible to the attack. Common Bostrychid genera are *Dinoderus*, attacking a variety of bamboos worldwide; *Heterobostrychus*, attacking a variety of timbers in Asia and Africa; and *Sinoxylon*, several species of which commonly occur in timber depots and sawmills in Asia. In Kerala, a study conducted by Mathew (1982) in government-owned timber depots recorded 13 species of Bostrychids, attacking over 20 species of timber. The Bostrychidae infest the sapwood of all sawn and seasoned timber, veneers and plywood, flooring timbers, window frames, massive doors, and beams in buildings. They are generally small (4–32 mm), dark in color, possess a hard body covering, and are elongate, cylindrical in shape. The larvae are whitish in color and pupate in their individual tunnel, transforming into the adult. Where starch is abundant, the life cycle is short and may be completed in 2–3 months. The flight holes vary according to species, from 3 mm to more than 10 mm in diameter. The Lyctidae infest sawn timber and plywood as well as manufactured wood. *Lyctus brunneus* and *Minthea rugicollis* occur in Asia and Africa.

The family Bostrychidae includes a number of important insect species, which are harmful to timber and timber products. Hence, the beetles are of considerable economic importance to forestry and the wood-using industries, and a few species have become important pests of timber, wooden works, and ancient structures in tropical countries. Bostrychidae are among those beetles that seem most perfectly adapted to a xylophagous way of life. Both as adults and larvae they feed on the woody tissues of their host plants. Most species gain their food from starches and sugars in the plant tissues on which they feed, but endosymbiosis with bacteria in mycetomes of the hind part of the mid gut is well-known in Bostrychidae. Beeson (1941) has reported that the powderpost beetles are not capable of assimilating cellulose. Bostrychids are almost never confined to particular host plants. Beeson and Bhatia (1937) recorded about 42 families, 145 genera, and 226 species of plant hosts in India, among which Caesalipiniaceae, Mimosaceae, Papilionaceae, Anacardiaceae, Euphorbiaceae, and Dipterocarpaceae were the most "popular" host plant families.

Although most Bostrychids are not host-specific and are often strongly polyphagous, some show preferences for particular hosts; e.g., some species of *Dinoderus* sp. normally breed only in bamboos (Beeson and Bhatia 1937). Adult Bostrychids tunnel in the bark in order to lay eggs, producing tunnels that are free of dust. The hatched larvae then bore in the sapwood in search of starch, producing tunnels that are packed with fine dust. This pattern of tunneling and the four jointed legs of the curved larvae enable this damage to be distinguished from that of the Lyctids. In fact, Bostrychid damage is not as common as Lyctid damage, probably because infestation commences with a tunnel bored by the adult in contrast to a Lyctus infestation that is initially completely invisible. Damage is principally confined to the sapwood of green hardwoods, although softwoods are occasionally found to be attacked, particularly if they have barked adhering (Beeson 1941). Bostrychids are essentially polyphagous, and it is exceptional for the food plant species to be restricted in one genus or one generic group of plants.

Beeson and Bhatia (1937) reviewed extensive studies on *Dinoderus* in their paper on the biology of Bostrychidae. In the tropics, *Dinoderus minutus* can breed throughout the year, and the maximum number of the generations is about seven

(Beeson and Bhatia 1937). The life history of *Dinoderus brevis* is stated to be very similar to *Dinoderus minutus*, but *Dinoderus ocellaris* Stephens hibernates as an egg and three or four generations in the year in north India and five generations in the year in Bengal.

The following insects were found to attack sawn timber and logs of rubber wood in Kerala: *Dinoderus* sp., *Heterobostrychus aequalis*, *S. anale*, *S. conigerum*, *Phaenomerus sundevalli*, *Minthea rugicollis*, *Platypus latifinis*, *P. solidus*, *Xyleborus similis*, *S. anale*, and *S. senegalensis*. Eradication of wood-boring insects is possible by applying heat. A temperature of at least 55 °C inside the timber must be maintained for a minimum of at least 2 h, depending on the actual temperature and circumstances. Heat treatment has no preventive effect.

Damage of wood/timber by wood borers. *Lyctusafricanus, Dinoderusminutus, Heterobostrychusaequalis Sinoxylonanale* and *Cerambycid beetle*

14.3 Goods and Services by the Forest Insects

14.3.1 Beneficial Insects

14.3.1.1 Silk Insects in Forests

Among beneficial insects, silkworms have a special status as they produce highly valuable silk. Though all silk species live on tree leaves, mulberry silkworms and Eri silkworms are considered domestic and managed on planted bushy species. Tasar silk culture is known as wild or forest sericulture. They feed on the leaves of a variety of forest trees that grow wild in tropical, subtropical, and temperate zones. The main tasar silk-producing countries of the world today are China and India. For centuries Indian raw silk has been gathered by the families of forest and hill tribes accounting for high export earnings. A distinct belt of humid, dense forest sprawling over the central and southern plateaus at an elevation of 600 m is the home of tropical tasar in the states of Bihar, Madhya Pradesh, Orissa, and Maharashtra and touches the fringes of Andhra Pradesh, Karnataka, West Bengal, Manipur, and Assam and the north Indian states, at an elevation of 700–2200 m, such as Jammu and Kashmir, Uttar Pradesh, and Himachal Pradesh.

Tasar silk is secreted by several species of the genus *Antheraea* (Saturniidae). India alone has at least eight species: *A. mylitta*, *A. assamensis*, *A. sivalika*, *A. roylei*, *A. compta*, *A. helferi*, *A. frithii*, and *A. andamana* (Jolly et al. 1968). Out of these, only *A. mylitta* has been exploited commercially and is the chief producer of tasar silk in the tropics. The temperate tasar insect is an interspecific hybrid (*A. proylei*, Jolly) evolved by crossing indigenous *A. roylei* Mr. with its Chinese counterpart *A. pernyi* G.M. The *proylei* silk is the finest tasar silk ever produced in India, and the insect has outrun its parents both quantitatively and qualitatively. Apart from being an achievement of great economic interest, the synthesis of *A. proylei* is a unique example of interspecific hybridization in insects, which, in spite of a great disparity in the chromosome numbers of parental species, has been successfully maintained internationally in the descending generations.

A. mylitta feeds primarily on *Terminalia tomentosa*, arjun (*T. arjuna*) and sal (*Shorea robusta*), and nearly two dozen food plants of secondary importance have been recorded as well, the more important of which are *Zizyphus mauritiana*, *Terminalia paniculata*, *Anogeissus latifolia*, *Syzigium cumini*, *Careya arborea*, *Lagerstroemia parviflora*, and *Hardwickia binata* (Jolly et al. 1968). In India, *T. tomentosa* is widely distributed as a common tree. In the traditional practice, the tasar larvae feed on irregularly distributed food plants in forests or along the embankments of paddy fields. This creates management problems resulting in losses due to pests, diseases, and natural hazards.

The forests that provide food for tasar silkworms are now being utilized in India mainly for fuel and timber, which are of less economic importance than the returns from silk. If these forests were completely diverted to tasar silk production, they could provide a significant increase in income for a vulnerable section of society, as has already been shown. There would also be environmental benefits. Silkworms excrete and dead remains also enrich the quality of the soil. The tasar silk industry has a significant agri-silvicultural potential for many forest-rich developing countries, and in particular for countries that wish to create employment and raise the standard of living of forest-dwelling peoples who may be lagging behind the rest of the country.

14.3.1.2 Pollinators

Insects, mainly bees, butterflies, dipteran flies, and others, help in pollination, which is the process of transferring pollen from a male part of a flower (anther) to the female part (stigma) to enable fertilization and the production of seeds. Landscape and forest management practices can help ensure the continued availability of pollinators and thereby increase the productivity of forests. The harvesting of trees affects pollinator species composition and diversity and plant–pollinator networks. A decline in pollinators due to habitat degradation and climate change is likely to have major consequences for natural forest regeneration. Many wild pollinators depend heavily on forests for nesting and forage, and the extent of forests and other natural habitats in a landscape plays a role in determining the species.

Insect pollinators

Insect pollinators

The literature regarding pollination of terrestrial tree species have shown a great account of insect pollination in crops and forestry species. The efficiency of insects belonging to various families of orders Hymenoptera and Diptera as successful pollinators of crops and forestry plants are well documented worldwide. Among entomophily, bee pollination was referred to as higher due to two reasons: (1) bees visit flowers for gathering food reward and thus reliably seek the flowers during all seasons and (2) flower constancy of bees is very high (Roubik 1989). The extent of bee pollination in agricultural crops and its impact on crop yield were assessed in detail by many reserchers, who have presented a vivid picture of pollination efficiency of various bee species in crop pollination. The same trend was observed in the case of various forestry species as well. Many species of Diptera were proved to be efficient pollinators in different important tree and shrub species. Reddi and Subba Reddi (1983) presented a detailed account of flower visitation by many species of flies and bees in *Jatropha gossypiifolia*, where out of 18 flower-visiting species, three species of bees and two species of flies have shown efficient pollination. Among bees, *Apis florae* and *Apis cerana indica* are the chief pollinators, and among Dipterans, *Sarcophaga orchidae* proved best in pollination efficiency. Active insect visitation resulting in efficient pollination was recorded in *Euphorbia geniculata* where many Dipterans and Hymenopterans were reported as frequent flower visitors (Reddi and Subba Reddi 1983). The pollination biology of *Santalum album* was also found highly influenced by bees and flies (Bhaskar 1992). Members of the family Syrphidae, Diptera, and a few bee species, namely *Apis cerana indica* and *A. dorsata*, were reported as major pollinators of sandal and mangrove plants (Remadevi et al. 2019) showing the highest flower visitation. Kinetics of insect pollinators in *Paulownia fortunei* was studied in detail by Kumar and Ahmad (2001), out of 12 species of flower-visiting insects, seven belonged to the family Apidae. Two species of Syrphidae were also recorded as chief visitors of this flower. Among bees, *A. dorsata*, *A. cerana indica*, and *Xylocopa fenestrata* were found as chief pollinators of *Paulownia* sp. Bees were reported as relatively most frequent flower visitors than the other insects in this case. Records of efficiency of bees and flies as chief pollinators in many important plant species in forestry and agriculture thus clearly demonstrate the significance of insect pollination.

Krishnan et al. (2012) identified the variables that influence the abundance and richness of the social giant Asian honey bee (*Apis dorsata*) and solitary bees in remnant forests in a coffee-growing landscape mosaic in southern India. Forest size had a positive influence on the abundance of colonies of *Apis dorsata*, which preferred forests with relatively open edges. The richness and abundance of solitary bee species were negatively influenced by forest size when the forest edge had a high density of large trees. Rehel et al. (2009) used a systematic assessment to identify the benefits of biotic pollination for NTFPs and crops in the Nilgiri Biosphere Reserve, India. They found 139 NTFP species considered important for local livelihoods; these were mainly leaves and fruits for medicinal and nutritional purposes.

In tropical forests, an overwhelming majority of tropical forest trees are animal pollinated, and many, if not most, species are bee-pollinated. The effects of an increased level of CO_2, elevated temperature, or changes in the length of the dry season on pollinating insects are not well documented. Increased drought, however, is known to lower the population densities of bees that use moist habitats as nesting sites. The decline in the number of nests associated with El Nino years has also been reported for stingless bees in Southeast Asia. Thus, drought may reduce floral resources as well as nesting sites for insect-pollinators, further decreasing the reproductive output.

Insect flower associations have long been a pivotal subject for many entomologists because of their economic importance in agriculture and because of the co-evolutionary history between flowers and pollinating insects. Adults of most butterfly species are effective pollinators and tend to visit a broad spectrum of plant species for nectar. Field observations, however, reveal that some flowers are frequently utilized by butterflies while others are not. In certain cases, flowers of particular plants are more preferred by particular butterfly species, and flower constancy is sometimes prominent. Flower constancy, which varies with both the species of butterfly and the species of plant, appears to be an outcome of learning through the recognition of rewarding flowers. Most butterfly species do not forage on all flowers available but often consistently visit specific flowers (Lewis 1989).

For a comprehensive understanding of the evolutionary associations between flowers and butterflies, it is essential to elucidate which floral features are involved in their foraging behavior. Insects are known to make use of a variety of sensory modalities in foraging, and the integration of visual, olfactory, and gustatory cues is usually involved in their orientation to and finding of food sources. Although such flower selection of insects is determined by various information from flowers (e.g., color, shape, scent, nectar, and phenology), visual and olfactory cues are thought, in general, to be the main stimuli that attract insects to flowers. It was also established that butterflies can perceive air-borne chemicals from food sources such as flowers, oak sap, rotten fruits, and so on and show high levels of sensitivity to diverse volatile compounds. Nectar of butterfly-pollinated flowers is characterized by high proportions of sucrose compared to the hexose, fructose, and glucose and by a high concentration of amino acids (Baker and Baker 1975).

14.3.1.3 Butterflies and Their Importance

In the India region (India, Pakistan, Ceylon, Burma, Andamans, and Nicobar), about 1400 species have been found, and some of them are the most beautiful in the world (Wynter—Blyth 1957). About 100 species of butterflies were collected from the Silent Valley National Park by Mathew and Rahamathulla (1992) and found that butterflies, like most other Lepidoptera, show distinct patterns of habitat associations. Extensive studies on butterflies of Western Ghats, Southern India, were carried out by Gaonkar (1996), which was the first study that took into account all 330 species in 166 genera belonging to 5 families recorded from this mountain range and the adjacent areas. An intensive survey of Nilgiris and its environs by Gunathilagaraj et al. (1997) revealed 104 species of butterflies. Kehimkar (2008) published the book, *The Book of Indian Butterflies*. It contains an illustration of 735 species of butterflies occurring in the Indian subcontinent. He described in detail the distribution, biology, host plants, and importance of butterfly gardens. Seasonal patterns in butterfly abundance and species diversity in four tropical habitats in the northern Western Ghats were studied. A checklist on butterflies of Western Ghats, Southern India, and butterfly species diversity related to plant diversity, foliage height diversity, and resource richness across vegetation types have also been documented (Kunte 1999). According to Kunte 2000, India has more than 1400 species of butterflies and 330 of them in the Western Ghats (a “hot spot”) alone, of which 37 are endemic. Singh and Bhandari (2003) studied the butterfly diversity in tropical moist deciduous forests of Dehra Dun valley. A total of 183 species of butterflies belonging to 128 genera and 5 families were recorded from the study area. The index significantly declined during the monsoon. It again increased significantly during post-monsoon. The species diversity was highest during autumn and lowest during winter. Since many butterfly species on the Western Ghats are indicators of particular (and species-specific) habitats, it is possible to identify ecologically important landscapes of this mountain range for conservation purposes, based on the diversity of species. The 330 species reported so far are dependent upon at least 1000 species of plants as larval host plants and as adult food plants, nectar resources, etc., many of which are also endemic to this mountain range. So, the occurrence of species of butterflies in a locality would also suggest the occurrence of their larval host plant species in that area. Only the maintenance of a contiguous belt of forest in different ecological zones, all along the Western Ghats, as it is at present, would ensure the continuation of this rich genetic diversity. A butterfly monitoring program is initiated by EMPRI with the intention to study and correlate the butterfly availability in various seasons/years in different parts of Karnataka (Remadevi 2020). It is planned as a citizen science endeavour facilitated through a identification App and field guides (Remadevi et al. 2020).

14.4 Factors/Challenges to Insect Diversity in Forests

Forests are known as carbon sinks as they live for many years and stock carbon years after year for a long time. Agriculture is getting expanded worldwide to meet the growing needs of a burgeoning population. An expansive increase in agricultural land could lead to the destruction of approximately 33% of the planet's remaining tropical and temperate forests, savannas, and grasslands. Habitat loss and species extinctions would be pervasive, and as the world's forests continue to diminish, there would be a loss in carbon sinks. Other ecosystem goods and services, such as potable water, food, timber and non-timber products, and recreation, would also be lost with the conversion of these natural lands to managed agricultural landscapes.

14.4.1 Climate Change

Based on the ecological interrelationship between forest and climate, it is very evident that climate change impacts forests and forests play a major role in climate change. Based on recent research findings, the annual rate of deforestation is 0.14% per year, with 2.3 million square kilometers lost between 2000 and 2012. The net carbon emission from deforestation and forest degradation, which can cause climate change, was high, and it has not changed significantly over the last two decades (Khaine and Woo 2015). Global forests have been changing over the past decades, and tropical forests have been significantly reduced by an annual loss of 2101 km^2/year. Species mortality through water deficiency was found to occur more in the tropical dry forests, and it severely affected trees of small diameter (Suresh et al. 2010).

As climate change affects forest species, insects on them are also affected, which is clear in some species but cannot be generalized. The direction of the effect of climate change can vary from positive to negative, and it is often difficult to disentangle indirect and direct effects, as well as tri-trophic interactions (Pureswaran et al. 2018). Many defoliators and bark beetles show better survival in high elevations than in the past. More research is needed on the impact of climate change on species and communities in subtropical and tropical forests. Climate change can either promote outbreaks or disrupt trophic interactions and decrease the severity of outbreaks. Most of the data available so far on forest insect epidemics are restricted to temperate and boreal ecosystems. In temperate climates, insects respond positively to temperature, and their abundance can peak at warm temperatures (Youngsteadt et al. 2015). Warm spring temperatures can also favor tree growth, advance budburst, and produce high-quality foliage that can potentially aid early larval feeding. Hot, dry summers can modify tree defenses and resistance to herbivory. Climate change can therefore either favor outbreaks or disrupt trophic interactions and decrease the severity of outbreaks.

It is often argued that the frequency and severity of *C. fumiferana* outbreaks in North America have increased in the twentieth century. Reports of forest decline are becoming more frequent, and habitat shifts are occurring throughout the continental USA, bringing to the limelight the importance of interactions involving drought, insects, and fire (Clark et al. 2016). Climate change is predicted to advance the phenology of the secondary host that is more abundant at the upper latitudinal edge, making it more susceptible to defoliation during outbreaks, and thus facilitating the expansion of the outbreak area into higher latitudes (Régnière et al. 2012; Pureswaran et al. 2015). In dry, tropical forests, high temperature and low precipitation decreased the growth and development of Saturniid caterpillars feeding on Salicaceae, compared to cooler, wetter conditions (Agosta et al. 2017). Young oak trees did not suffer greater herbivory when exposed to *L. dispar* larvae under drought conditions and inadequate winter chilling disrupted synchrony between *L. dispar* and its host trees, potentially decreasing the severity of outbreaks (Foster et al. 2013). Relationships between insect pests and their natural enemies change as a result of global warming, resulting in both increases and decreases in the status of individual pest species. Quantifying the effect of climate change on the activity and effectiveness of natural enemies for pest management will be a major concern in future pest management programs.

14.4.2 Land Fragmentation

Land-use change and land management practices can fragment and degrade pollinator habitats and affect the connectivity of pollinator communities, which could, in turn, affect pollinator breeding success. Connectivity among fragmented habitats promotes the movement of pollinators between patches and may help reduce the impacts of fragmentation. Agricultural lands adjoining forests or natural areas benefit from pollinator services, and animal-pollinated crops therefore achieve higher fruit set. The proportion of wild habitat required to provide such additional pollination services for crop plants may differ by crop type and other landscape variables. Invasions by alien plants not only alter the diversity of pollinator species available for native plants but could also affect plant–pollinator networks. Habitat heterogeneity is a significant driver of pollinator abundance and diversity. Consequently, the composition of a landscape is likely to have significant implications for the floral and nesting resources of pollinators and therefore their presence and abundance. Urban gardens, forest patches, and semi-natural green spaces in the rural–urban interface are particularly important in providing pollination services in rural and peri-urban areas. There is evidence of pollen limitation in several plant species due to recent climatic changes. Given the crucial ecological role of pollination services in landscape resilience, food security, and livelihoods and the likely increasing impacts of climate change on such services, understanding the ways in which forest management practices can benefit pollinator communities is imperative. At the forest management scale, the measures may include establishing baselines of pollinator diversity and abundance and monitoring these over time; where fire is used as a management tool, maintaining a mosaic of burned and unburned pollinator habitat; developing field guides for pollinator management based on knowledge of the biological attributes of pollinator species in an area and flowering phenology and synchrony; drawing on and learning from indigenous and local knowledge about pollinators and phenologies; employing forest management practices such as selective logging, thinning, prescribed burning, mowing, and coppicing in ways that increase the heterogeneity of tree communities; in forest management planning, allowing temporal (as well as spatial) habitat heterogeneity; retaining dead standing and lying wood in forests and ensuring sufficient bare ground for cavity-nesting and ground-nesting bees; regulating the grazing of domestic and wild ungulates in forests to minimize competition for floral resources between those ungulates and wild pollinators; and, in restoring degraded forests,establishing tree species at densities sufficient to enable their effective pollination.

14.4.3 Invasive Insects

At present in India, due to scarcity and hike in prices of conventionally preferred timber species like teak, sal, rosewood, mahogany, etc., dependence on fast-growing, nonconventional plantation timber is increasing. Currently, the market is flooded with a number of fast-growing species with low natural durability, and also many timber species are imported from different countries and used for various purposes like the manufacture of plywood, block boards, matchboxes, packing cases, handicrafts, furniture, building material, and also paper and pulp. A total of 24 species of insects, 7 of which were of plant quarantine importance, were intercepted in logs imported to India through Madras from the Far East in 1990 (Krishnasamy et al. 1991). The important species were *Ceresium versutum, Cerobates sexsulcatus*, *Heterobostrychus aequalis*, *Opisthenoxys ochraceus*, *Platypus curtus*, and *Xylotrechus brevicornis* (each from Malaysia) and *Xyleborus perforans* (from Malaysia, Papua New Guinea, and Vietnam). A survey of different depots in Kerala, India, revealed the occurrence of 53 species of beetles as pests of one or more of 46 species of stored timber (Mathew 1990). Many insects reach our forests through weeds and seeds as well. Rao and Remadevi (2006) reported 55 species of insects and 22 species of fungi from imported timbers screened from 6 mjor ports in India. Import of many biologicl materials also attract many invasive pests to India.

14.4.4 Pollution

Probable relationships between the impact of air pollution on forests and the epidemic behaviour of insect pest populations are outlined on the basis of field observations reported in the literature. Different outbreak patterns along the impact gradient suggest the distinction between three types of pest species, which are differently favoured or handicapped according to the air contaminant concentration. Since air pollution effects must be considered to concern each food chain level directly and/or indirectly, a wide variety of interferences with population dynamic processes can be expected. The most probable ones are shortly described, emphasizing the urgent need for experimental evidence as to the modes of action of air contaminants upon forest insects.

14.4.5 Habitat Disturbance and Forest Fires

Fire is a natural and important disturbance in many forest ecosystems. It may have immediate adverse effects on pollinators, but subsequent regeneration and changes in land use will determine future pollinator species composition, abundance, and diversity. Mosaics of burned and unburned habitats recover faster than large tracts of burned habitats. Carbone et al. (2019) found that recurrent fires, especially wildfires, have a negative effect on Lepidoptera abundance and a positive effect on Hymenoptera, with Lepidoptera larvae much more susceptible to direct fire effects.

14.4.6 Pest Outbreaks

Unlike agriculture, pest management in forestry poses several challenges. Pest management is particularly relevant in the production/plantation forestry sector, where productivity is greatly affected by pest outbreaks and diseases. Conventional chemical methods are unsuitable for large areas under plantations due to the hazards and widespread damage they inflict on the environment. Therefore, safer agents with appropriate application methods need to be identified to meet the current challenges. New technology such as genetic transformation by recombinant DNA techniques that confer resistance to plants against insect attacks is gaining strength now in the horizon of agriculture and horticulture systems. Transgenic plants are however not a panacea for solving all the pest problems, and secondary pests may not be controlled in the absence of chemical sprays.

Eco-friendly approaches such as the use of biological agents are considered the best alternatives to chemical pesticides today. Entomopathogens, viz., bacteria, fungi, viruses, protozoa, and even nematodes, are increasingly exploited for the development of bio-pesticides, especially in the agricultural sector. Many entomopathogens are remarkably virulent, replicate inside the insect body and cycle through the population quite effectively by efficient transmission methods. This self-replicating ability and the capacity to cause high levels of mortality are considered the strong positives for their use as bio-pesticides. Among the different entomopathogens, fungi are perhaps the maximum exploited organisms, and many fungal products are registered worldwide to control insect pests, mainly in agriculture.

Substantial resources of entomopathogens, especially fungal BCAs, have been raised through public–private partnerships for pest management in agriculture, horticulture, and agro-forestry. Many of these investments in this sector are making it easier for countries to procure the necessary commodities for pest interventions. But relatively little investment has been made in the forestry systems through which these goods can be effectively delivered to those in need. Hence, coverage with IPM remains very low in forestry systems, and meeting the targets continues to be a formidable challenge.

Bio-pesticides have already been proved to be one of the feasible alternatives to chemicals in agriculture and therefore merit for a serious try in forestry too, obviously with carefully designed application methods. A strong IPM program intending to yield good success should advisably have different components integrated into it, which will strengthen it to produce the best effects. As such, different classes of potential microbes need to be simultaneously exploited and integrated into an IPM program for better results.

14.5 Possible Solutions/Management

Diverse Forest insects play key roles in the maintenance of forest ecosystems providing valuable goods and ecosystem services. Climatic and environmental factors and the anthropogenic interventions lead to the imbalance in their diversity which results in pest outbreaks, disruption of pollination services etc. which need management mesures in an ecofriendly regime.

14.5.1 Integrated Pest Management

Insects and diseases cause a considerable impact on the health of the forest ecosystem in India. The damages are either from the native pests or from the invasive exotic pests coming from exotic locations or from other parts of the country. Pest management methods in the forestry sector have rarely received the same amount of attention as in the agriculture sector and are still not very refined and defined. It has special relevance to production and plantation forestry, where productivity is the primary concern. Forest insect pest management differs from pest management in agricultural and horticultural systems because of the relative complexity and stability of the forest environment. An important component of this stability is the rich fauna of natural enemies attacking most of the forest insect pests. Effective pest management in forestry requires reliable information: information on the pests themselves, their biology, ecology and distribution, relationships between the herbivorous insect pests and their natural enemies, their impacts on forest ecosystems, and feasible methods of control.

Until the late 1940s, little was done in India to control forest pests. In the early 1960s, a variety of methods were used to control forest insect pests and diseases, including mechanical, silvicultural, chemical, and biological methods, chemical control being the most commonly used. By the 1970s, crop protection specialists had become aware of the adverse side effects of dependence on chemical pesticides, including pesticide resistance, the occurrence of secondary pests, pest resurgence, toxic residues, environmental damage, and human health hazards. This led to the realization that alternative approaches, including cultural, biological, and genetic tactics, were needed to provide long-term, effective protection against damaging pests. Therefore, a concrete IPM package with minimum use of chemical insecticides, focusing mainly on bioagents, is the need of the hour to tackle the noxious pests efficiently. The best approach to managing pest problems is to combine prevention and control strategies to meet natural resource management objectives. This approach is called integrated pest management (IPM). The IPM concept involving the integration of cultural methods, mechanical methods, use of semichemicals (attractants), use of natural products, conservation/augmentation of biological agents, and application of need-based chemicals is the most successful strategy currently available for pest management.

Forest Integrated Pest Management or Forest IPM is the practice of monitoring and managing pest and environmental information with pest control methods to prevent pest damage to forests and forest habitats by the most economical means. From the forest perspective, integrated pest management (IPM) can be defined as the maintenance of destructive agents including insects, at tolerable levels by the planned use of a variety of preventive, suppressive, or regulatory tactics and strategies that are ecologically and economically efficient and socially acceptable. IPM is the only method feasible and applicable in forest pest management. IPM practices in forestry vary from region to region according to the habitat and the types of forests. It combines the aims of productivity, environmental sustainability, and cost-effectiveness. In agriculture, in recent times, bio-pesticides have been strongly emerging as feasible alternatives to chemical insecticides. They are increasingly being recommended as an integral component of IPM (Ashok Kumar et al. 2020). Therefore, they deserve a serious try in forestry too, especially in nurseries and young plantations with carefully designed application methods. Safe and less problematic agents need to be first identified for integration into IPM. In this context, biological control methods can offer great dividends, which could yield sustainable results. Biopesticides based on microbes are yet to become popular in pest control programs, especially in the forestry sector.

14.5.1.1 Biological Control

Constraints on the use of chemical pesticides may lead us to the development of biological control options and their implementation in an integrated pest management (IPM) program. The need to reduce or eliminate the use of conventional chemical pesticides, both in agriculture and forestry, has fostered a search for alternative products and strategies that have a much lower impact on human health and the environment. Naturally occurring biological control agents, plant-derived target-specific insecticides, and pest-resistant plants obtained through conventional breeding are among the better-known and most accepted alternatives. Biological control has a long history of use in pest management and has gained renewed interest because of problems encountered with the use of pesticides. Production and use of biological insect control agents is the challenge of the future for pest management.

Biocontrol is an attractive option because it is self-sustaining, is economical for large areas requiring treatment, and has a relatively low environmental impact. In the search for more environmentally friendly methods of insect control, biological methods may prove as effective tools in the battle against forest insect pests. Several extremely diverse groups of microbial parasites occur in the forest ecosystems, which are ubiquitous in distribution and potential regulators of host populations. The importance and utility of parasites and predators as bio-control agents of insects are well documented, and many of them are practically used for insect pest management. Microsporidia is an interesting group of organisms that affect almost all animal lineages from very lower groups to the most highly evolved mammals, including man.

Biological Control Using Fungal Entomopathogens

Unlike other biological control strategies, conservation biological control does not require the introduction or augmentation of natural enemies. Instead, it relies on modification of the environment or management practices to protect and encourage natural enemies that are already present within the system. This improves their ability to control pest populations in a reliable way and is only possible if the biology, behavior, and ecology of both the pests and their natural enemies are understood. Unfortunately, for most entomopathogenic fungi, our understanding of their ecology and epizootiology is incomplete. The majority of examples of conservation biological control to date have been for arthropod natural enemies. However, similar approaches are relevant to entomopathogenic fungi where fungi are principal enemies of the target pest and where their ecology and epizootiology are understood.

The entomopathogenic fungi are a diverse assemblage of fungi with one thing in common: they infect and cause disease in insects and other arthropods. By understanding the factors that promote or inhibit epizootic development, strategies can be identified that ensure favorable conditions for the proliferation of entomopathogenic fungi and consequently reliable epizootics.

Metarhizium infected Hyblaea puera and Atteva fabriciella

Metarhizium-infected *Hyblaea puera* and *Atteva fabriciella*

Biocontrol Using Microsporidian Parasites

The microsporidia are a potential group of microbial parasites of insects but largely ignored for use in pest control, mainly because they are relatively poorly understood. Interestingly, these organisms assume importance from two contrasting angles, one from the point of view of their utility for insect pest control and the other because of their severe harmful effects on beneficial insects such as honey bees and silkworms, including also the many aesthetic and charismatic butterfly species. Currently, microsporidia also assume significant medical importance as some species have been found associated with humans, especially in immuno-compromised individuals. The occurrence of microsporidia in forest Lepidoptera is very less known, at least in India, and our study is a pioneering effort to document the prevalence of these parasites in butterflies and moths and also to elucidate the bio-control potential of some of the species against selected important lepidopteran forest pests (Remadevi et al. 2010).

Since many microsporidia are potential endoparasites, the observed association of these organisms with butterflies is indicative of their possible role in regulating the butterfly populations in nature. Laboratory experiments also resulted in very high horizontal transmission with 88% in the case of *Pd* microsporidium and 90% in the case of *Cp* microsporidium in their respective hosts. These two microsporidia also showed vertical transmission to the extent of 72 and 82%, respectively. This observation tends to suggest the possibility of prevalence of vertical transmission among microsporidia of many other butterfly species. Also, due to their reported pathological effects on the hosts, they could be implicated as one of the conspicuous mortality factors in butterfly farming. These observations may necessitate screening of female butterflies after egg laying to raise microsporidia-free stocks in butterfly farming for eco-tourism. The findings also highlight the need for maintaining good hygiene while raising butterfly population in the parks. In-depth studies on microsporidians associated with butterflies will enable us to generate more knowledge on the dynamics of these host–parasite systems, which in turn would help in developing methods to eliminate microsporidiosis during butterfly rearing.

Microsporidia are undoubtedly prevalent in the tropical forest ecosystem, but relatively few studies have been conducted in these regions. Studies in India on microsporidia from forest Lepidoptera are very few and it was the severity of defoliation and damage caused by the teak moth as a defoliator that prompted our search for endemic microsporidia, which could be exploited for bio-control purposes. Entomopathogenic microsporidia have been the subject of investigation of several workers worldwide for possible development of biopesticides (Maddox et al. 1998).

A large number of butterfly species are also known to be infected by microsporidia, but their impact on the host butterflies is rather poorly understood. Microsporidia have been isolated from several butterfly species, and their pathology was studied reasonably well at least in some species. Infection of butterflies by microsporidia assumes greater significance in the wake of the current growing interest in butterfly farming as a strong ecotourism product. Apart from their possible utility in biological control, the constant threat posed by these emergent pathogens to butterfly farming also necessitates systematic studies on the occurrence and association of these parasites in the natural populations of various butterfly species.

14.5.1.2 Management Methods for Wood-Destroying Termites

Although termites are excellent decomposers of deadwood and other sources of cellulose: They become a serious problem when they attack standing trees, logs, and crops. Therefore, effective control methods have to be extensively studied and exploited. Physical methods are a very popular method of preventing subterranean termite attacks on wooden structures. Toxic physical barriers (Chlorfenapyr) and nontoxic physical barriers (sand or gravel aggregates, metal mesh, or sheeting) have been used as physical termite barriers. Other physical methods, including heat (45 °C for 30 min), freezing (liquid nitrogen −20 F), electricity (90,000 V), and microwaves, were effectively used in many studies. Chemical treatment measures are one of the various techniques used to reduce the infestation of termites. Several termiticides containing active ingredients such as bifenthrin, chlorfenapyr, cypermethrin, fipronil, imadacloprid, and permethrin are registered for termite control around the world under various brand names and many biological alternatives are also being used (Ahmed et al. 2006; Monica et al. 2009).

Although chemical control is a proven means of protection from termites, its excessive use is harmful to the environment. New methods of termite control are always being developed by researchers. Plant-derived natural products, entomopathogenic fungi, nematodes, and bacteria (Devi et al. 2006) are some of the alternative methods being developed against termites.

14.6 Conservation Efforts

14.6.1 In the Frame of Wild Protection Act 1972

In the Wildlife (Protection) Act, 1972 of India and Amendment, 1991, 452 species and subspecies of butterflies belonging to nine families have been included. Schedule I part IV of the Act includes 128 species of butterflies (*Amathusideae*, 3; *Danaidae*, 3; *Lycaenidae*, 47; *Nymphalidae*, 37; *Papilionidae*, 14; *Pieridae*, 6; *Satyridae*, 18). Schedule II part II includes 304 species. Schedule 3 includes 304 species of butterflies (*Amathusidae*, 10; *Danaidae*, 2; *Erycinidae*, 5; *Hsperiidae*, 3; *Lycaenidae*, 114; *Nymphalidae*, 73; *Papilionidae*, 21; *Pieridae*, 21; *Satyridae*, 55), and schedule IV includes 20 species of butterflies (*Danaidae*, 4; *Lycaenidae*, 9; *Nymphalidae*, 3; *Pieridae*, 4). The wildlife (Protection) Act, 1972 has enough provisions for the protection and conservation of butterflies. Butterfly conservation depends not just on committed conservationists, scientists, and teachers but on informed and interested individuals such as the common public, policymakers, officials, and NGOs to implement the law effectively (Gunathilagaraj 1998).

14.6.2 Forest Management

There has been little systematic research on the role of forest management practices in maintaining wild pollinators. An important knowledge gap exists on relationships between pollen limitation and forest plant recruitment as a result of reduced seed set. There are also large gaps in understanding on metapopulation dynamics, functional diversity, and pollination networks of pollinators at the landscape scale across diverse management regimes. Few long-term studies exist that could provide data for projecting the impacts of climate change on forest pollinators. Inventories and quantitative data are lacking on pollinator-dependent forest species that produce wood and non-wood products and on the economic value of pollination services related to these. Indigenous and local knowledge is still undervalued and underused in scientific research.

14.6.3 Phytosanitary Measures for Timber Import in India

India is a signatory to WTO–SPS agreement and International Plant Protection Convention (IPPC). Until recently, the import of wood to the country was regulated by (Regulation of Imports into India) Order 1989, treating wood as a plant material. In November 2003, the rules were updated through plant quarantine (Regulation of import into India) Order 2003. This order has stringent clauses and was amended in further orders (February, March, and May 2004) and further amended in 2005. Aspects of regulation and implementation are dealt with by Sathyanarayana Rao and Remadevi (2006).

14.7 Recommendations

14.7.1 Promotion of Habitats for Wild Pollinators

The impacts of forest management on pollinators should be addressed multi-sectorally, with the involvement of farmers, pastoralists, indigenous peoples, local communities, forest managers, beekeepers, and other land custodians and stakeholders. Policy instruments are needed that encourage practices in the forest and agriculture sectors to help maintain and increase pollinator services, especially given the potential impacts of climate change. These may include mechanisms to facilitate exchanges of knowledge among stakeholders in the forest and agriculture sectors and to help determine trade-offs between interests and ecosystem services; payments for pollination services and other economic incentives to support pollinator-friendly landscape management; and comprehensive guidelines for ensuring the maintenance of pollination services in forests and landscapes.

14.7.2 Multicropping and Diversification

Insect biodiversity may well relate to vegetation structure and complexity. The habitats with the least structure, such as annual monocropping and degraded grasslands, showed poor species richness and diversity. Agroforestry systems possess species composition more similar to natural forest compared to annual cropping or degraded grasslands. Although species diversity in the latter systems was still relatively high, species composition differed significantly from that in natural forests. These altered and disturbed habitats contained more phytophagous species and a low proportion of predatory species. Higher intensity of land use causes not only a biodiversity decrease but also a complete change of species composition. As cocoa agroforests nowadays cover large areas of tropical land, there is general recognition that they are biodiversity reservoirs for rainforest species. Natural forests, as well as all natural vegetation types in the tropics, are worthy of protection because of their high species richness and ecological potential. The governments and citizens of all tropical countries (not only in Amazon) are responsible for developing agricultural practices that prevent complete ecosystem conversion and loss of unique biodiversity. We believe that various agroforestry systems are able to conserve some of the original biodiversity of original forests and can form a suitable reservoir for some insect species that occur in primary tropical forests.

14.7.3 Maintaining Healthy Forests

One of the potential programs and projects that could be implemented to promote forest conservation and afforestation, contributing to the NDC target of the country under the Paris Agreement, is to conduct research for climate-resilient silviculture: develop/identify appropriate temperature, pest and fire tolerant species, and silviculture practices to cope with changing climate and its impacts. The forest sector in India has a huge potential to mitigate climate change by achieving an additional 3 billion tons of carbon sequestration by 2030. However, achieving this would require serious efforts toward conservation, restoration, and regeneration of the country's forests. The biodiversity, especially that of forest insects, plays a major role in both positive and negative ways by virtue of being major herbivores, but at the same time performing many ecosystem functions of pollination, biological pest regulation, being in the food chain, and regulating the healthy growth and sustenance of the ecosystems.

There is widespread public opposition to the use of chemical pesticides in the forest and a growing demand for environmentally benign, host-specific, safe pest control agents. In general, biological control seems particularly suited to forest insect problems since the relatively stable environment of a forest guarantees freedom from such adverse effects as interference by pesticides or disturbing agricultural practices. The natural complexity and stability of forest ecosystems make forest environments amenable to the practice of biological control in its broadest sense. The use of natural enemies of forest insect pests to regulate their numbers below the economic threshold level is a practical strategy. In the case of forestry, there are only limited success stories on the management of pests using predators or parasitoids of insect pests. There is a great need to intensify research on biological control, even from the point of conserving the biological diversity of the region.

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Chapter 15
Status, Issues, and Challenges of Biodiversity: Marine Biota

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15.1 Introduction

Indian marine resources comprise all shores, lagoons, backwaters, mangroves, salt marshes, deltaic plains, mudflats, gulf waters, tidal flats, wetlands, coral reefs, and open marine areas. Surrounded by the Bay of Bengal from the east, the Arabian Sea from the west, and the Indian Ocean from the south, the east coast, west coast, Andaman and Nicobar Islands, and Lakshadweep form the significant areas of marine biodiversity in India. Indian coastline (ca 7500 km) and exclusive economic zone (EEZ) (2.02 mn km^2) harbour all the marine resources of India, including dinoflagellates, diatoms, seagrass, seaweeds, mangroves, fishes, reptiles, sea birds, marine mammals, and members of different species of animal kingdom strictly found in the oceans. Due to its tropical placement and size (29% of the world's ocean), the Indian Ocean is rich in biodiversity, making India one of the 12 marked mega biodiversity countries and a biodiversity hotspot region where the richest but highly endangered biodiversity is observed. The west coast constitutes oceanic atolls and stretches to 0.86 million km^2, it shows an intense upwelling due to southwest monsoon, and thus very high biodiversity is observed. Similarly, the east coast of 0.56 million km^2 constitutes continental islands and a weaker upwelling due to northeast monsoon; thus, a lesser diverse species richness is observed. The exclusive economic zone (EEZ) area around Andaman and Nicobar Islands (0.6 million km^2) is rich in coral reefs.

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15.2 Status in Terms of Number and Diversity Indices

15.2.1 Diatoms

Diatoms are single-celled algae encapsulated in the transparent opaline silica with different shapes, sizes, and unique patterns. These are majorly used for filtration, account for over 40% of the photosynthesis in the world's ocean, and support ocean life as a source of food and energy. Diatoms are death deposits on the ocean floor and form diatomaceous earth, also known as kieselguhr, which is used to improve skin, nails, teeth, bones, and hair. Diatoms are a source of silica and are also used to treat high cholesterol levels and constipation.

Indian estuaries and coastal waters account for at least 25% of the world's pennate and centric diatoms combined. The west coast (148 spp. from 22 families) shows relatively higher biodiversity than the east coast (102 spp. from 17 families). Both coasts show the dominance of Naviculaceae (22 spp.), followed by Biddulphiaceae (16 spp.), Lithodesmiaceae (15 spp.), and Thalassiosiraceae (12 spp.). Bacillariaceae, Biddulphiaceae, Chaetoceracae, Naviculaceae, Thalassiosiraceae, Thalassionemataceae, and Rhizosoleniaceae are the most diversely available families in distribution, whereas Stellarimaceae, Stephanodisceae, Hemidiscaceae, Streptothecaceae, and Heliopeltaceae are found only from the west coast.

15.2.2 Dinoflagellates

Dinoflagellates are unicellular protists with two dissimilar flagella found in marine and freshwater environments. They vary in shape, size, forms, and functions. Some make their food using light through photosynthesis, some are parasitic, and some show bioluminescence. They may produce neurotoxins, too, which affect their neighbouring organisms during an algal bloom, and if humans consume such affected organisms, it may lead to ciguatera or paralytic shellfish poisoning.

Indian coasts harbour at least 90 species of dinoflagellates out of ~2000 species reported in the global marine environment. The highest number of species was found from the family Dinophyceae, with 18 reported species, followed by Peridiniaceae (13 species) and Ceratiaceae (10 species). The west coast estuaries show higher species richness, with 76 species reported from 10 different families, whereas 15 species from 7 families were reported from the east coast.

15.2.3 Seagrass

These are the plants found in marine environments. They are believed to be evolved from the land plants millions of years ago, and like their land counterparts, they also have roots, stem, and leaves and may bear fruits and flowers. Seagrass provides food and shelter for fishes, epiphytic organisms, planktons, and large marine animals. The Indo-Pacific environment supports seagrasses' growth and development, resulting in the world's highest seagrass diversity. Oceans absorb 25% of global carbon emissions and 15% of which is stored by seagrass. A total of 14 species belonging to 7 genera were reported from Palk Bay (11 species) and Gulf of Mannar Biosphere Reserve (13 species), west coast, Thiruvananthapuram, Andaman and Nicobar Islands (9 species), and Lakshadweep (7 species) with members of *Thalassia* and *Syringodium* being dominant.

15.2.4 Bacteria

Marine bacteria are comprehensively explored for their antibiotic and pharmaceutical roles in novel and potent drugs, but due to difficulty in their laboratory cultivation, we still lack crucial information about them. Genera *Pseudomonas*, *Bacillus*, *Micrococcus*, *Alteromonas*, and *Flavobacterium* dominate the marine environment (Sinimol et al. 2016; Jayanth et al. 2001; Nithya and Pandian 2010). *Bacillus* sp. and *Streptomyces* sp. found in Indian coastal waters were reported to have broad-spectrum antimicrobial activity and antibiotics generating abilities (Chandramohan 1997). Anand et al. (2006) reported that marine bacterial strains, such as *Bacillus* and *Vibrio* sp. associated with sponges isolated from the Gulf of Mannar, were able to produce antibiotics, which is the first report on isolation and identification of antibiotic-producing bacteria (Anand et al. 2006).

15.2.5 Virus

Although viruses are more common and dominant in number (109 and 1010 viruses l^{-1}) in marine environments, less is known about them due to time-consuming and laborious conventional counting and analysis methods. Both biotic and abiotic factors influence the viral growth in deep-sea sediments. Viruses may profoundly affect microbial loop dynamics and biogeochemical cycling of organic matter. They are well-known pathogens that cause lysis of bacteria and phytoplankton and microalgal senescence. Marine viruses also play an essential role in producing dimethyl sulfide, which is the most abundant volatile sulfur compound in marine environments and accounts for about 50% of the overall biogenic sulfur flux to the atmosphere (Das et al. 2006).

15.2.6 Fungus

The presence and role of fungus in deep-sea sediments have received only scant attention than the fungus knowledge close to the seashore. The mangrove ecosystem is ideal, as most of the fungi here are detritus-dependent. Kohlmeyer and Kohlmeyer (1979) described five indigenous deep-sea filamentous higher fungi: *Abyssomyces hydrozoicus*, *Allescheriella bathygena*, *Bathyascus vermisporus*, *Oceanites scuticella*, and *Periconia abyssa* (Kohlmeyer and Kohlmeyer 1979). Raghukumar and Raghukumar (1998) isolated barotolerant fungi *Aspergillus ustus* and *Graphium* sp. colonies from the Arabian Sea and Bay of Bengal, India (Raghukumar and Raghukumar 1998).

15.2.7 Seaweeds

Seaweeds refer to three taxonomic groups that have different pigment compositions: Ochrophyta (brown algae), Chlorophyta (green algae), and Rhodophyta (red algae). These taxonomic groups have complex evolutionary life history schemes. The first seaweed recorded from the Indian Ocean was a specimen of *Amphiroa* (Rhodophyta) collected by Hermann in 1672 (Sahoo 2001). Linnaeus reported *Sargassum granulatum* (*Fucus granulates*) (Ochrophyta, Phaeophyceae) and *Turbinaria turbinate* (*Fucus turbinatus*) from Indian waters (Linnaeus 1753). The maximum number of seaweed species from India, i.e., 411 species, was reported by Dixit (1968). The first comprehensive evidence distribution of Indian waters was provided by Krishnamurthy and Joshi (1970).

The checklist by Untawale et al. (1983) described 604 seaweed species, including 156 species belonging to Chlorophyta, 141 species to Ochrophyta, and 307 species to Rhodophyta (Untawale et al. 1983). Oza et al. (2011) revised the checklist and reported 841 species along the Indian coast (Oza et al. 2011). A total of 844 species, including different forms and varieties, are reported and are distributed among 217 genera (Fig. 15.1) (Venkataraman and Raghunathan 2015). Recently, the Botanical Survey of India (BSI) compiled the occurrence of 865 taxa from Indian waters, of which 442 species belong to Rhodophyta, 212 to Chlorophyta, and 211 to Ochrophyta (Mantri et al. 2020). Table 15.1 reviews the abundance of seaweeds reported from the Indian coasts.

Among the different classes of algae, Rhodophyta is documented as a species-rich phylum with approximately 434 acknowledged species, followed by Chlorophyta (216 species), Phaeophyta (191 species), and Xanthophyta (3 species). Gujarat's and Tamil Nadu's coastlines harbor maximum seaweed diversity (Ganesan et al. 2019). Gujarat alone has a coastline of 1600 km and houses 198 species, of which 109 species from 62 genera belong to Rhodophyta, 54 species from 23 genera to Chlorophyta, and 35 species from 16 genera to Ochrophyta (Jha et al. 2009).

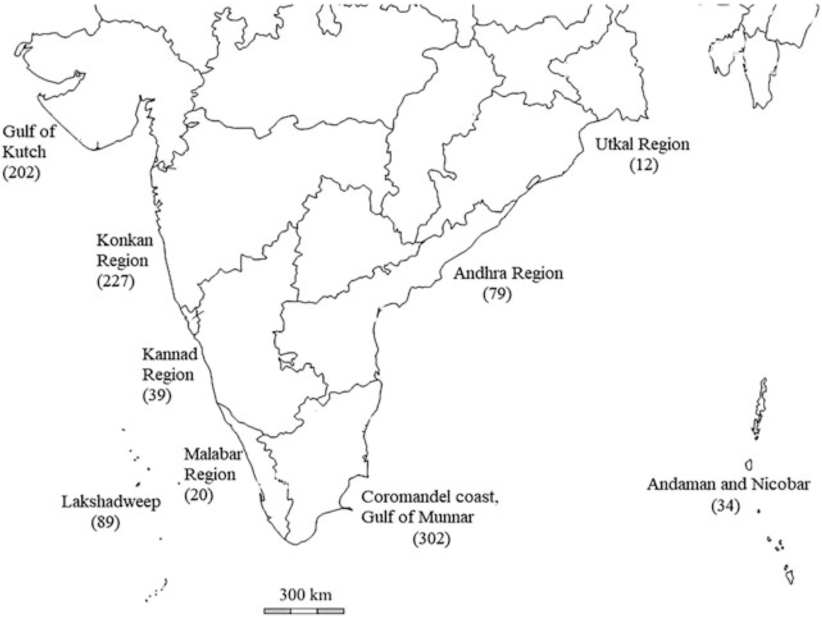

Fig. 15.1 Distribution of seaweed across the Indian coast. Adapted from Venkataraman and Raghunathan (2015)

Table 15.1 Comparative data of checklist reported by previous researchers (Mantri et al. 2020)

Checklist	Title	Rhodophyta	Chlorophyta	Ochrophyta	Total
Krishnamurthy and Joshi (1970)	Genera	98	36	33	167
	Species	256	130	136	522
Untawale et al. (1983)	Genera	120	44	39	203
	Species	307	156	141	604
Sahoo (2001)	Genera	138	45	18	221
	Species	420	184	166	770
Oza et al. (2011)	Genera	136	43	37	216
	Species	434	216	191	841
Rao and Gupta (2015)	Genera	138	46	50	234
	Species	442	212	211	865

Dhargalkar and Deshmukhe (1996) recorded 20 red algae species, including *Hypnea musciformis*, *Chmpiaparvula*, *Haloplegma duperreyi*, *Gracilaria corticate*, *Polysiphonia* sp., *Laurencia obtuse*, *Spyridia fusiformis*, *Champia parvula*, etc. from Dwaraka coast of Gujarat (Dhargalkar and Deshmukhe 1996). Tamil Nadu spanning along a coastline of 1076 km enriched with 282 species, of which 146 belong to Rhodophyta, 80 to Chlorophyta, and 56 to Ochrophyta. A total of 43 species of red algae were reported from the seven different coasts of Mandapam during 1983 and 1984. *Gracilaria foliifera*, *Gracilaria textorii*, *Gracilaria verrucosa*, *Kappaphycus alvarezii*, *Portieria hornemannii*, *Hypnea musciformis*, and *Acanthophora spicifera* are recorded from the inter-tidal rock shore of India's South-Eastern coast (Bhagyaraj and Kunchithapatham 2016).

Karthick et al. (2013) documented 13 genera and 29 species of green algae, 9 genera and 23 species of brown algae, and 13 genera and 20 species of red algae from the Islands (Karthick et al. 2013). However, poor records are still available from the Andaman Islands (Venkataraman and Raghunathan 2015). Jadiye and Rao (2007) reported a new species, *Dasya ulhasii* Sonali U. Jadiye and P. S. N. Rao sp. nova (Rhodophyta, Ceramiales) from the Dapoli coast of Maharashtra, India (Jadiye and Rao 2007). Shores of Gujarat, Maharashtra, and Goa share three common red algae *Gracilaria corticata*, *Champia robusta*, and *Acanthophora specifera*. Ambhore and Whankatte (2016) reported *Corallina berteroi*, *Gelidium pusillum*, and *Gracilaria edulis* from the Raigad coast of Maharashtra (Ambhore and Whankatte 2016). From Maharashtra's coasts, a total of 73 species of seaweeds were reported, including 45.21% species of Rhodophyta, 28.77% species of Chlorophyta, 23.29% species of Phaeophyta, and 2.73% species of Cyanophyta. Species of *Ulva*, *Chaetomorpha*, *Enteromorpha*, *Sargassum*, *Padina*, *Amphiroa*, *Jania*, and *Gracilaria* are common in this region. Economically important algal species occurring along this coast are *Porphyra*, *Gracilaria*, *Gelidium*, *Ulva*, and *Sargassum* spp. (Waghmode 2017). The data investigation revealed that the diversity of red algae is more than green and brown algae. Seaweeds are used as food (vegetable, salad, soup, porridge, and pickle) and fertilizer in many countries. They are a good source of phycocolloids such as agar and carrageenan, widely used in industries. Thivy (1960) was the first to record the distribution of economically significant seaweeds, specifically alginophytes and agarophytes along the Indian coast (Thivy 1960). The presence of sulfated polysaccharides in their wall matrix makes them financially important. Seaweeds are altogether used for the production of phycocolloids. India has almost 46 seaweed-based industries, 21 are agar manufacturing, and 25 are alginate manufacturing industries (Rao and Mantri 2006). In India, seaweed resources are mainly exploited to produce commercially essential phycocolloids. The carrageen production is not happening in India due to the lack of quality raw materials like *Kappaphycus*, *Eucheuma*, *Gigartina*, and *Chondrus*, but *Hypnea* is available adequately. Carrageenan requirement in India is met only through imports. Central Salt and Marine Chemicals Research Institute (CSMCRI), in collaboration with PEPSICO India Holdings Ltd., Gurgaon (Haryana state), took an initiative to start pilot-scale cultivation of *Hypnea* species throughout the year and to begin indigenous carrageenan production in the country. *Kappaphycus alvarezii* has also been domesticated as a raw material for carrageenan production. Presently, approximately 25 actively functioning seaweed-based chemical industries collect seaweeds from the Indian coast's particular sites. Tamil Nadu is the hub of such sectors.

Gelidiella acerosa and *Gracilaria edulis* are the two principal sources for agarophytes utilized by the Indian agar industry. *Gelidiella* is the preferred source as it produces the best quality and quantity of agar. The overexploitation of seaweed resources resulted in exhaustion and a significant shortage of raw material stock.

Therefore, conservation and judicial harvest strategies for sustainable production and marine algae utilization are now advocated. Hence, the increasing demand for raw material for industrial utilization has encouraged Central Salt and Marine Chemicals Research Institute (CSIR-CSMCRI) to start programs on seaweed bio-prospecting, cultivation, and technical development expertise for the large-scale cultivation of edible and pharmaceutically essential seaweeds. These significant discoveries pointed out that there is a necessity and urgent need to increase the effort to survey the new marine zones to realize the real wealth of our country. To explore and document the seaweed diversity of the island of the Gulf of Mannar, Tamil Nadu, and the Gulf of Mannar, Bioreserve Trust works collectively on a project sponsored by CSIR-CSMCRI (Mantri et al. 2020). The work is still in progress.

15.2.8 Sea Animals

India covers 8000 km as a coastline in terms of the marine environment. Marine mammals include a diverse group of aquatic and ocean-dwelling mammals. Aquatic mammals also breathe air from their lungs, just like land animals. Primarily *Cetaceans* (whales, dolphins, and porpoises), *sirenian* (dugong), and *otters* (sea otter and marine otters) are present in waters of the Indian subcontinent.

15.2.8.1 Cetaceans

This group comprises 90 species, having all the animals, mainly whales, dolphins, and porpoises. *Cetaceans* are further divided into two different suborders: *Mysticeti* (baleen whales) and *Odontoceti* (toothed whales, including dolphins and porpoises). In Indian subcontinent waters, 30–33 species belong to the Cetaceans group, with one freshwater dolphin and one Sirenia. Whereas 11 species of baleen whales are present, as shown in Table 15.2. *Cetaceans* come under the category of aquatic animals but are mammals; they come to the surface to breathe and vary from medium to large. *Cetaceans* have a layer of fat under their skin for insulation, which is called blubber and this layer of insulation varies in every species. In the case of sperm whales, it is 30 cm in thickness and whereas it is 70 cm thick in the case of Bowhead whale 27 (Marine Mammals of India 2021).

Suborder Odontoceti (Toothed Whales): The primary characteristic of members of this order is that they are small in size and are numerous compared to order *Cetaceans*. There are approximately 70 species in six families. *Platanistidae* or river dolphins are among the group members found in India's Ganges-Indus River. The majority of oceanic dolphins are well represented in the northern Indian Ocean. *Phocoenidae* is found in the coastal region and is considered true porpoise. Like

Table 15.2 Different species of the order Cetaceans and their presence in the Indian subcontinent

	Species	Records from India
A.	Order: Cetaceans (whales, dolphins, and porpoises) Suborder: Odontoceti—toothed whales Family: Delphinidae—marine dolphins	
1.	*Steno bredanensis* (rough toothed dolphin)	Southwest and southeast coast
2.	*Sousa chinensis* (Indo Pacific humpback dolphin)	Coastal waters of east India
3.	*Sousa plumbea* (Indian ocean humpback dolphin)	West coast
4.	*Stenella coeruleoalba* (striped dolphin)	Andaman Nicobar, Lakshadweep, and along with peninsular India; southwest and southeast India
5.	*Delphinus delphis/capensis* (common dolphin)	Indian Peninsular region
6.	*Tursiops aduncus* (Indo-pacific bottlenose dolphin)	Found around peninsular India and the Lakshadweep and Andaman Nicobar group of islands
7.	*Pseudorca crassidens* (false killer whale)	Southeast and southwest coasts and the island systems
8.	*Orcinus orca* (killer whale)	Goa, Maharashtra, Pondicherry, Tamil Nadu, Lakshadweep, and Andaman Nicobar Islands
9.	*Globicephala macrorhyncus* (short-finned pilot whale)	Salt Lake near Calcutta, Cuddalore, Tamil Nadu
B.	Order: Cetaceans (whales, dolphins, and porpoises) Suborder: Odontoceti Family: Phocoenidae—porpoises	
1.	*Neophocaena phocaenoides* (Indo Pacific finless porpoise)	Across all the coastal states
C.	Order: Cetaceans (whales, dolphins, and porpoises) Suborder: Odontoceti Family: Physeteridae—sperm whales	
1.	*Kogia breviceps* (pygmy sperm whale)	Visakhapatnam and Trivandrum
D.	Order: Cetaceans Suborder: Mysticeti Family: Balaenopteridae	
1.	*Megaptera novaeangliae* (humpback whale)	Along the west coast of India, until Kanyakumari and southern Gulf of Mannar
2.	Order: Sirenia Family: Dugongldae	The Gulf of Kutch, the Gulf of Mannar and Palk Bay, and the Andaman and Nicobar Islands

Cetaceans, the size of a toothed whale varies from 1.6 m to 18 m in the case of dolphins and long sperm whales, respectively. Members of this group are found in a wide range of habitats, from freshwater to deep parts of the oceans.

15.2.8.2 Ganges Shark

Glyphis gangeticus, generally known as Ganges Shark, is endemic to India. The primary habitat of Ganges Shark is Hooghly River in West Bengal, but it is also found in Ganga, Brahmaputra, and Mahanadi rivers in Bihar, Assam, and Orissa. There is no confirmed report for its presence in oceans and sea, and Ganges Shark comes under critically endangered species in the IUCN Red List (WWF 2020).

15.2.8.3 Mugger Crocodile

Three crocodilians have been reported so far in India, out of which one is the mugger crocodile, and the other two are the gharial and the saltwater crocodile (Da Silva and Lenin 2010). The mugger crocodiles are restricted to Indian subcontinents. With an estimated wild population between 2500 and 3500, they are reported from over ten states (Whitaker and Andrews 2003).

15.2.8.4 Tortoise

The most popular tortoise species found in Indian rivers is the Indian star tortoise. The smallest sea turtles, *Lepidochelys olivacea*, commonly known as olive ridley sea turtle, are also found at Odisha's coasts. Leatherback sea turtle (*Dermochelys coriacea*) and green sea turtle (*Chelonia mydas*) have been reported from Andaman and Nicobar. Indian Ocean Reef harbors critically endangered hawkbill sea turtle (*Eretmochelys imbricata*).

15.2.8.5 Corals

Coral reefs provide food and shelter to marine life and prevent the coastline from erosion. Coral reefs are considered a most primaeval and active ecosystem. The major four types of reefs in India (Fig. 15.2) are as follows:

1. Andaman and Nicobar Islands
2. Gulf of Kutch
3. Gulf of Mannar
4. Lakshadweep

Calcareous skeleton helps in the formation of the structure of reefs. The hydroids keep on joining for a time ranging from thousand to million years and giving rise to such reefs (WWF 2020). Reefs can vary vastly in their structure and complexity and can be divided into three major types.

a. *Fringing reefs*: Growth of fringing reefs is very close to shore and outspread into the sea like an inundated platform.

Fig. 15.2 Major coral reef areas in India (Muley et al. 2002)

b. *Barrier reef*: In this case, reefs are detached from the land by extensive water spreads and follow the coastline.
c. *Atolls*: Atolls are characterized by their circular ring of reefs surrounding a lagoon, a low-lying island, typical in the Indian and South Pacific oceans.

Andaman and Nicobar Islands

There are roughly 530 islands in Andaman and Nicobar Islands, and fringing types of reefs are found along the coastline, which is in good condition. Corals found in this region are *Acropora, Porites*, *Pocillopora*, *Montipora*, *Heliopora*, *Tubipora*, and *Favia.*

Threats

The decline of most of the coral reefs near Port Blair, Navy Bay, Flat Bay, and Reef Island is due to sedimentation and mud deposition. Sedimentation leads to the invasion of the crown-of-thorns starfish *Acanthaster planci*, potentially destroying whole reefs quickly. Other threats include disparaging fishing methods like blast fishing and cyanide fishing. Similarly, coral bleaching caused due to the removal of algae from corals turns them white, causing stress, proving lethal for the reefs. Because of development along the coastline, corals are under threat due to pollution.

Dust from plywood industries is a significant cause of pollution of corals. Agricultural runoff includes fertilizers and pesticides, which cause corals' death.

Gulf of Kutch

Northernmost reef of India is Gulf of Kutch. Corals that are present in this area are of a fringing type. Massive forms of corals are found in the Gulf of Kutch. Corals like *Acropora*, *Pocillopora*, *Stylophora*, and *Seritopora* that come under the category of branching corals are absent. In this region, diversity of *scleractinian* corals is very poor. Only 20 genera are reported out of 60 genera reported worldwide in India. Common species found in all the Gulf of Kutch islands are *Montipora venosa*, *Cosinaria monile*, *Hydnophora excess*, *Turninaria petata*, *Goniastrea pectinata*, *Platygyra sinensis*, *Cyphastrea serialia*, *Porites compressa*, and *Goniopora stutchburyi*. Species such as *Siderastrea savignayana* and *Acanthastrea hillae* are reported only from the Gulf of Kutch.

Threats
Oil spills in the Gulf of Kutch are a pervasive problem and are a significant threat to corals. Pollution caused by industrial discharge and deposition of waste on corals leads to corals' death. Another threat is overfishing, which is not suitable for the ecosystem. In this area, cement industries play a role in degrading corals by depositing sand on reefs. Mining of gigantic corals and sand has also caused severe damage.

Gulf of Mannar

Fringing reef-type corals have been reported from the 21 islands between Rameswaram and Tuticorin. The most common genera of corals present in the Gulf of Mannar are *Acropora*, *Montipora*, and *Porites.* Seagrass beds and olive ridley turtles are also present along with corals. In India, only 28 genera are reported so far. Some species are restricted to this area, such as *Montipora millepora*, *M. jonesi*, *M. manauliensis*, *M. edwardsi*, *M. exserta*, *Acropora rudis*, *A. valenciennesi*, *A. microphthalma*, *Porites exserta*, and *Porites mannarensis*. Other common species reported only from Gulf of Mannar and Palk Bay are *Montipora monasteriata*, *M. informis*, *M. spumosa, M. turgescens*, *M. venosa*, *M. verrucosa*, *M. digitata*, *M. millepora*, *M. manauliensis*, *Acropora digitifera*, *A. secale*, *A. intermedia*, *Pocillopora verrucosa*, *Porites mannarensis*, *P. exserta*, and *Goniopora stutchburyi*.

Threats
Modern fishing techniques and destructive methods like fish bombing threaten corals in the Gulf of Mannar. For agar industry, farmers harvest seaweeds; this harms corals. Sewage discharge and agricultural runoff are also responsible for the loss of

corals. Industrial expansion and discharge of waste and effluents in water affect the coral reefs and the environment.

Lakshadweep

Atoll type of reefs is present in Lakshadweep. There are 12 atolls, 3 reefs, 5 submerged banks, and 36 islands from the Lakshadweep archipelago. Islands in Lakshadweep are dominated by *Acropora* spp. and *Porites* spp. Rarely young colonies of *Psammocora* spp., *Stylophora* spp., *Pocillopora* spp., and *Leptoria* spp. are located on the reef flats. The species diversity decreases from the lagoon area toward the landward direction. The reason behind decreasing species diversity is the disturbance caused by boats' operation, which further leads to sedimentation (Nobi et al. 2009). *Astrocoeniidae*, *Pectiniidae*, and *Trachyphylliidae* families are absent in this region. Common species from Lakshadweep island are *Acropora humilis, A. muricata* (A. formosa)*, A. intermedia,* A. *hyacinthus*, *Pocillopora verrucosa*, *Euphyllia glabrescens*, *Galaxea fascicularis*, *Psammocora contigua*, *P. haimeana*, *Pavona maldivensis*, *P. clavus*, *Fungia danai*, *Podobacia crustacea*, *Hydnophora microconos*, *Favites abdita*, *Goniastrea retiformis*, *Platygyra daedalea*, *P. sinensis*, *Leptastrea bottae*, *Porites solida*, *P. lichen*, and *P. minicoensis*. A few species restricted to these islands only are *Montipora spongiosa*, *Acropora abrotanoides*, *A. hemprichi*, *Psammocora haimeana*, *Acanthastrea echinata*, *Porites rus*, and *Alveopora superficialis* (Venkataraman and Raghunathan 2015).

Threats
Lakshadweep Island's threat to corals is due to natural processes like erosion, siltation, and predation by starfish-like *Acanthaster planci*. Starfish causes white band disease in coral reefs. Human activities such as construction along the coast and vegetation removal cause disturbance and severe threats to coral reefs. Sewage discharge and agricultural runoff that consist of fertilizers and harsh chemicals affect, and cargo transports cause severe destruction of many coral reefs.

15.3 Possible Impacts

Loss of biodiversity will affect our food and medicines and will have a daunting effect on our existence. Following are the few possible impacts of the loss of marine biodiversity.

15.3.1 Ocean Acidification

The ocean acidification, caused due to increased absorption of atmospheric carbon dioxide, endures a direct impact on marine organisms, specifically organisms with calcareous skeletons or shells, including crustaceans, mollusks, and phytoplankton. Extreme climatic events like erosion and flooding depleted the natural marine environment. Such events disturbed marine life, particularly in coastal habitats such as mangroves and seagrass beds, which are dynamic breeding grounds and possible CO_2 capture zones (Baswapoor and Irfan 2018). Elevated CO_2 levels lead to the dissolution of the exoskeleton in the case of calcifying animals, resulting in damage to sensory structures such as nasal cavity arrangement in reef fish (de la Haye et al. 2012) and antennules in hermit crabs (Spicer et al. 2007).

15.3.2 Changes in the Behavioural Pattern of Organisms

Climate changes due to anthropogenic activities directly influence the behavior of marine species. A climatic change alters the diversity, abundance, and dispersal of marine species. It also affects feeding, breeding, development, and relationships between species. Rising temperatures lead to various behavioural pattern changes among the species. Some species adapt to temperature changes, whereas many species drift toward the poles. Many coral species vanish due to the loss of unicellular algae on which they feed and shelter. As reported by Baswapoor and Irfan (2018), coral reef bleaching has caused damage to the Gulf of Kutch and Lakshadweep's reefs. Exposure to copper leads to reduced heartbeat rate and disrupted other social structures, mating, aggression, and other behavioural processes (Rovero et al. 2000). Polluted environment disrupted perception and cognition behaviour among marine animals (Elwood 2001). Change in seawater chemistry leads to impaired cognition and affects sensory functions destroying neural formation in coral fish (Domenici et al. 2012).

15.3.3 Coral Mining

Coral reefs are dwelling places to hundreds of marine creatures, but not all are obliged. Many fishes graze on them and change their morphology, making them more vulnerable to other physical and chemical extortions. Predation by the crown and triton snail, living on the ocean bed and feeding on the thorns starfish's young ones, limits their population. Commercial harvesting of triton shells resulted in a decline in its population, and there were no sufficient snails to feed on the starfish.

Thus, starfish population proliferates, which in turn feeds on coral reefs. This problematic situation is prominent in the Gulf of Mannar and Lakshadweep islands in India (Baswapoor and Irfan 2018). Unfortunately, without distinguishing between live and dead corals, they have mined aggressively and produced lime and built houses. Such activities intensively resulted in the loss of large patches of low-lying reefs. This impact is catastrophic in the Gulf of Mannar, where 250 m^3 of coral reefs are mined every day (Rajasuriya and Karunarathna 2000). In the 1980s, the mining of coral sands was rented to a cement company in the Gulf of Kutch. About a million tons of coralline sands, including live corals, were mined every year, killing a large percentage of the coral reefs. Auspiciously, the lease was not renewed later. However, the destruction was already done, and the loss of coral cover was more than 50% in the Gulf of Kutch (Baswapoor and Irfan 2018).

15.3.4 Land Expansion

The exploitation of water resources and land expansion leads to rapid biodiversity loss. Noyyal River, which had formerly served the city's water requirements, was destroyed due to the geographical expansion of Coimbatore city in the recent span (Anil et al. 2014). Pragatheesh and Jain (2013) reported heavy metal pollution (including cadmium, lead, chromium, zinc, and mercury from the electroplating, dyeing, industrial effluents, jewellery industries, sewage, and urban runoff) toward the biotic life in the Noyyal (Pragatheesh and Jain 2013). A Similar situation arises due to the spatial expansion of Kolkata, which led to extreme changes in the biodiversity of the East Kolkata Wetlands and the Sundarbans. In Goa, due to absurd beach enhancement schemes and reclamation of sandy beaches for recreational activities and to increase tourism, there was a loss of dunes and associated flora and fauna (Wafar et al. 2011).

15.3.5 Introduction of Invasive Species

The fishing pattern more frequent in India is the collection of live baits, which are used for Tuna fishing and collection of ornamental fish for marketing (Baswapoor and Irfan 2018). Alien fish started migrating toward newer habitats and ecosystems, where they inhabit empty niches and compete with native species for food and space (Pimentel et al. 2002). Raghavan et al. (2008) reported five ornamental invasive fishes viz *Gambusia affinis*, *Oreochromis mossambicus*, *Xiphophorus maculatus*, *Osphronemus goramy*, and *Poecilia reticulata* from the Chalakudy River in the Western Ghats, which is a global biodiversity hotspot under threat in Kerala (Raghavan et al. 2008). Introduced fishes amend the aquatic ecology by changing water quality and are also responsible for the extinction of native fish through predation and resource competition (Pimentel et al. 2002). This makes Chalakudy

River a high urgency area for executing conservation and management actions to be needed. These introduced species act as a significant source of ecological destruction that may be alarming if ignored.

15.3.6 Unsustainable Tourism

In the last few years, the growing coastal tourism has produced environmental messes by severely altering the native ecological ambiance in which the indigenous species have flourished for generations. Kovalam, a coastal village of Kerala, India, has been standing at the verge of destruction and needs more initiatives from society to protect Kovalam from the consumerist's destructions due to urban-industrial culture (Ghosh and Datta 2017). In Andaman and Nicobar Islands, plastic, oil, and solid sewage waste are significant issues of concern due to unsustainable tourism (Baswapoor and Irfan 2018).

15.3.7 Pollution

Industrialization and urbanization along the coastlines are putting these ecosystems under immense pressure. Global climatic change is likely to set an additional stress on them. Sustainable development of marine ecosystems might diminish the stress on them and aid in conserving biological diversity. Expansion along shorelines, oil and gas extraction, offshore aquaculture, emission from agriculture, and waste discharges from industries have altered habitats and poisoned coastal fish harvests (Baswapoor and Irfan 2018). Carbon dioxide emissions from human activities and natural resources make the ocean acidic, and acidic water is not suitable for corals, shellfish, and plankton to survive (Nammalwar et al. 2013).

15.4 Possible Solutions

We depend on the ocean for the food we eat and the oxygen we breathe in. Burdens on marine biodiversity are accumulating speedily, but we can minimize these pressures by deploying scientific solutions and policies to improve the marine ecosystem's health.

The cumulative loss of marine biodiversity is an ecological problem and causes an economic crisis. There is a need to implement strong protections and sustainable fishing practices to prevent more drastic biodiversity loss. We need to stop overfishing, rebuild overfished stocks through catch limits and ecosystem-based fisheries management, and establish well-managed and highly or fully protected marine protected areas (MPAs). Governments need to implement rules against practices such as overexploitation, specifically overfishing and poaching. One significant problem nowadays is the intensive use of plastics that end up as ocean debris and contribute to killing thousands of marine species every year through habitat destruction. The only possible solution limiting these plastics is storing edible materials in nondisposable containers, using a recyclable water bottle, carrying a reusable bag when shopping, and recycling whenever possible.

15.5 Conservation Efforts

The coastal marine ecosystems have a major contribution to India's economy. Humans' remains depend on marine assets for their livelihood and recreational and commercial objectives including fishing, medicine, and tourism. Similarly, marine organisms also depend on marine resources for food, shelter, and breeding. This interdependence is crucial and essential to maintaining a balance between them. Unfortunately, marine environments are deteriorating at an alarming rate. The factors accountable for this destruction are the exploitation of species, the introduction of alien species, pollution from industries, agriculture areas, urbanization, excessive use of water resources, and habitat loss. Because of all these circumstances, valuable marine resources are becoming vulnerable to natural and anthropogenic environmental changes. Marine ecosystem degradation cannot be resolved by the traditional policies; rather, integrated coastal zone management programs and projects are required, which will report all the factors that influence the coastal zones.

Rapid development and rising population would cause an upsurge in natural resources along the coast. Environmental destruction and over-exploitation will erode marine and coastal biodiversity unless remedial actions are undertaken. With a coastline of 8129 km, India has an exclusive economic zone (EEZ) of 2.5 million km^2. EEZ act as an essential link between the marine and terrestrial ecosystems; hence, their conservation is vital for maintaining ecological balance (Nammalwar et al. 2013). However, practically this zone remains neglected and suffers from the nonattendance of conservation and development. For sustainable use of marine diversity, various conservation and management strategies are recommended for India's social and economic development.

15.5.1 Conservation Strategies by Government

15.5.1.1 Convention on Biological Diversity (CBD)

India became a CBD signatory in 1994. CBD relies on achieving Aichi Biodiversity targets by 2011–2020 (Convention on Biological Diversity 2004). The primary goals of CBD are the following:

1. Strategic Goal A: To address the fundamental causes of biodiversity loss by mainstreaming biodiversity across government and society.
2. Strategic Goal B: To reduce the direct burdens on biodiversity and encourage sustainable use.
3. Strategic Goal C: To improve the prestige of biodiversity by conservation of species, their ecosystems, and genetic diversity.
4. Strategic Goal D: To increase the benefits from biodiversity and ecosystem services.
5. Strategic Goal E: To enhance implementation through participatory planning, knowledge management, and capacity building.

15.5.1.2 Marine Protected Areas (MPAs)

The human community has converted the oceans into wastelands. Protection of marine species requires protection of their distinctive habitats and requires inhibition of unlawful hunting of aquatic species. Therefore, significant protected areas are required for marine habitat conservation and preservation. In India, the first Marine National Park came into existence in 1980 in the Gulf of Kutch, followed by the Gulf of Mannar and Wandoor Marine National Park in the South Andaman (Nammalwar et al. 2013; Saxena 2015). Marine Protected Area is a wide range of protected areas worldwide for marine conservation. These areas are managed with some conservational principles and serve as habitat and breeding ground for many species, preservation, scientific research, and recreation. India has 36 coastal and marine protected areas, out of which five are for the protection of coral reefs with a total area of 5319 km^2 (Baswapoor and Irfan 2018). The Ministry of Environment and Forests developed a practical strategy to manage the reef resources and recommended the sustainable utilization of coral reefs. Management of coral leaf is acknowledged in India's National Conservation Strategy and Environment Action Plan (UNDP 1997).

15.5.1.3 Coastal Management Policies

The Government of India has advised the Coastal Regulation Zone (CRZ) Notification, 2011, under Environment Protection Act, 1986 (Bhatt and Vivekanandan 2013). Accordingly, there are four coastal management zones:

1. Coastal Regulation Zone 1 (CRZ 1) consists of ecologically delicate areas including coral, coral reef-associated biodiversity, mangroves, mudflats, sand dunes, marine parks, national parks, sanctuaries, reserve forests, biosphere reserves, salt marshes, horseshoe crab habitats, turtle nesting grounds, seaweed beds and nesting grounds of birds, and the geomorphological features that play a primary role in maintaining the integrity of the coast. No new construction shall be allowable in CRZ I areas.
2. Coastal Regulation Zone II (CRZ II) consists of established areas close to the shoreline and lie under government administrative boundaries.

3. Coastal Regulation Zone III (CRZ III) consists of all open areas counting the coastal seas and excluding those classified as CRZ-I, CRZ-II, and CRZ -IV.
4. Coastal Regulation Zone IV (CRZ IV) consists of the Andaman and Nicobar and Lakshadweep islands.

15.5.1.4 Marine Fishing Regulation Acts (MFRA)

Fishing and pollution are supposed to be two main threats to coastal and marine biodiversity. Marine Fishing Regulation Acts (MFRA) and Comprehensive Fishing Policy are two primary instruments designed for regulating fishing operations to sustain the fisheries and biodiversity. Limiting the number of mechanized boats, spatial fishing constraints, seasonal closing of fishing, guidelines to regulate fishing mesh size, use of bycatch reduction devices (BRD), and turtle excluder device (TED) are monitored, but the execution of these measures are still a challenge.

15.5.1.5 National Plan for Conservation of Aquatic Ecosystems (NPCA)

It is a centrally sponsored scheme, formulated in 2015, and currently being implemented by the Union Ministry of Environment and Forests (MoEF). NPCA is a single conservation program for both wetlands and lakes. Ramsar convention 1971 provides guidelines for the conservation and wise use of wetlands and their resources.

15.6 Initiative from Indian Institutions

The only devoted research Journal where the researchers prefer to publish their discoveries and findings is the Seaweed Research Utilization, an open accessed journal. Researchers from approximately 80 nations provide the available information concerning the diversity, lavishness, and distribution of marine organisms through the Census of Marine Life (CoML), a global association of researchers (Mantri et al. 2020). Ocean Biogeographic Information System (OBIS), initiated and sponsored by CoML, is also a network of researchers belonging to 500 institutions from 56 countries. Rutgers University, USA, started the first OBIS database and consequently, in 2001 OBIS was linked with Global Biodiversity Information Facility (GBIF) as an assistant participant. In India, CSIR-National Institute of Oceanography (NIO) is developing an electronic catalog and digitization of Indian Ocean biota and marine biological crews. Recently, CSIR-NIO, underneath the program entitled bio search: Marine biodiversity database of India, initiated the digitization of seaweed collections alongside the Indian Ocean (Kakodkar et al. 2013). Even though this initiative is welcomed, the information provided along with the digital herbarium is elementary, and there is a necessity to incorporate more information on the diagnostic characters, distribution, ecology, application, conservation status, utility, and available published literature. Adding to this pipeline, CSIR-National Chemical Laboratory (NCL), Pune, has developed SAMPADA—cost-effective, handy, compatible software—for digitizing seaweed collected and submitted in the Indian institutions (Chavan et al. 2005). "DbIndAlgae" is a similar kind of initiative from the Central University of Punjab, Bathinda. It is a freely accessible first online database for identifying and cataloguing marine algae of India aimed at easy access and effective propagation of marine algal information. By July 26, 2019, DBIndAlgae comprises 51 species of marine algae belonging to 28 genera of Indian records divided into three phyla, viz Phaeophyta, Chlorophyta, and Rhodophyta. The database gives information concerning unique user ID (UUID), classification, distribution, and DNA sequence data, along with image and identification characters with key references (Bhushan et al. 2016).

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Chapter 16
Diatoms: the Living Jewels and their Biodiversity, Phycosphere and Associated Phenotypic Plasticity: A Lesson to Learn from the Current Pandemic of Coronavirus

Vandana Vinayak, P. V. Bhaskar, Lalit Kumar Pandey, and Mohd Jahir Khan

16.1 Summary

Global pandemics in the last few centuries were caused by organisms that were unknown to the human race, and many of these crossed over from animal hosts to infect humans. Zoonotic strains of bacteria are largely responsible for the global spread of illnesses like diphtheria, food-borne diseases, cholera, brucellosis, etc., while viral strains are known to cause Chikungunya, Ebola, Japanese encephalitis, AIDS, and various forms of influenza (Christou 2011) including Covid-19. Many of these crossover infections are attributed to various factors including exposure of humans to zoonotic pathogens due to increased human–animal interactions and over-population (Karesh et al. 2012). Another important factor considered responsible for the increase in infections by novel strains globally is climate change. From an Indian perspective, it is expected that diseases from novel strains of pathogens from diverse hosts (vectors-mainly insects), water, air, birds, and animals (chicken, rodents, bats, etc.) shall increase due to climate change (Singh et al. 2011). Oceans and freshwater bodies are important reservoirs of such unknown organisms as it collectively covers more than 70% of the earth's surface area. Aquatic microbes, including phytoplanktons, bacteria, fungi, and viruses are one such group of

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organisms that can serve as a source of new pathogens, toxins, and metabolites to fight against future pandemics.

Keeping in mind the above, we discuss in detail the importance of diatoms in a post-Covid world as a source of diverse associated microbes that may have importance in the future. Diatoms are siliceous autotrophs that constitute an important component of the aquatic phytoplankton community which is identified by its unique and intricately designed silica-based frustules. As phototrophs, diatoms play an important role in (1) fixing atmospheric carbon, (2) sustaining the aquatic food-web as a member of the primary producers that form the base of the food pyramid, (3) diverse elemental and geochemical cycles, and (4) climate mitigation (regulating concentrations of atmospheric gases like CO_2 and O_2, production of halides and sulfur aerosols, etc.). Diatoms are diverse and robust, and are found in most aquatic systems, including freshwater, marine, and brackish water and under extreme climatic conditions from tropics to poles. The diatoms also harbour diverse microbes within the environment surrounding them but close to their cell wall called phycosphere. These microbes include bacteria, fungi, and viruses, which closely interact with the diatoms. The objectives of the chapter are to discuss the progress made in Indian waters (freshwater and marine waters) on diatom diversity research and the impact of environment variables, pollutants, and other chemical moieties on its morphology and shape, with special attention on the phycosphere communities and their interactions with diatom host and the role of diatoms in imparting toxicity, causing harmful blooms, transferring toxins to the grazers, and in turn causing human fatalities.

The abundance and diversity of diatoms in freshwater ecosystems like lakes, rivers, and ponds are discussed. Although diatoms are diverse, the predominance of centrale diatom *Cyclotella* sp. in some specific water bodies is unique. In studies of the rivers (both seasonal and perennial) and lakes of north India, it was found that salinity influenced the thickness of silica frustules and their porosity. Also, apart from the endemic *Cyclotella* sp., various other species belonging to genera *Fragilaria*, *Tabularia*, and *Hantszchia* co-existed with them. Moreover, the abundance of diatoms was different in these studies. Interestingly, diatom cell abundance varied with season and their abundance was during spring>summer>monsoon>autumn>pre-winter and winters. The diatom abundance peaked at temperatures between18 and 22 °C, and Pennales were predominant in these lakes and rivers (Vandana 2012). Unlike freshwater ecosystems, the marine environment around the Indian peninsula has diverse forms of diatoms whose distribution is controlled by diverse environmental factors. In the Arabian Sea, monsoonal upwelling and the resultant increase in nutrients control the blooms of diatoms. Moreover, grazing by micro-zooplankton also has an impact on the diversity of the diatom community. In the Bay of Bengal, the preponderance of a few diatom species was largely influenced by the riverine influx, light availability, and nutrients. Moreover, nutrient ratios (N:Si > 1) appeared to support diatom growth. In view of the changing environment and growth conditions, the challenges for future research in monitoring the diatom population and diversity were delineated. The role of phycosphere and the associated microbes including bacteria, fungi, and viruses are discussed in detail to assess microbial diversity and its roles in pathogenicity, toxicity, and symbiotic interactions. The diatom exudates or exopolysaccharides (EPS) form a matrix in the phycosphere and may support the carbon demand of the bacterial population. The relationship of fungi and viruses with diatoms is largely fatalistic to the host diatoms. The possibility of an increase in fungal and viral infections of diatoms in changing environmental conditions is discussed. A detailed discussion on the different types of viruses infecting diatoms and the significance of such infections in releasing dissolved organic matter (DOM) and fueling the microbial loop and its role in geochemical cycling is also discussed.

Apart from these, diatoms cause nuisance blooms due to the toxin domoic acid (DA), as a result of which blooms of a few diatom species can result in fish death and cause fatalities in humans. This aspect of toxic blooms, along with other toxins like polyunsaturated acids (PUA) and oxylipins, their frequencies, and a probable increase due to climate change, is also addressed. In the penultimate section, the impact of metals on diatom size, pollutants like drugs on the cell morphology, sewage on the growth and tolerance, and plastics for attachment is highlighted. In the end, the section addresses the possible challenges and the solutions that can be applied to harness the potential of diatoms in a post-Covid era. The need for a concerted conservation effort at various administrative levels is highlighted, and a set of recommendations are put forth.

16.2 Introduction

The re-occurrence of viral diseases turning into pandemics has always laid risks on human lives (Restifo 2000). The danger is probably due to antigenic shifts, which produce new strains because of the recombination of two viral strains, which is far from being controlled (Carrat and Flahault 2007). Of the viral infections, acquired immune deficiency syndrome (AIDS) caused by the human immunodeficiency virus (HIV) has been the most serious of viral infections due to unprotected sex infected workers (Levy 1993). The outbreak of new avian influenza, which appeared in South East Asia in late 2002, and the resultant antigenic shift led to the emergence of new and novel subtypes of viral infection becoming pandemic (Guan et al. 2002). The current global situation due to the outbreak of the corona virus ever since December 31, 2019, is a similar example of how a silent gene shift has given rise to six different strains infecting and killing people worldwide (Salem et al. 2020; Ramaiah and Arumugaswami 2020; Loeffelholz and Tang 2020). This is due to the sudden invasion of the novel corona virus, which had its outbreak at Wuhan city, China, in December 2019, resulting in a global health emergency (Huang et al. 2020). It is believed that this virus has originated from bats and has crossed the human immune barrier, thus resulting in highly contagious flu-type symptoms for which no drug or vaccine has yet been developed (Poon and Peiris 2020). The resultant disease has come to be known as Covid-19 and has been declared pandemic by World Health Organization (WHO) (Lai et al. 2020). One thought which haunts the common man is whether this is the last health challenge we are facing. The threat to cripple the human race would be by this single corona virus, or are there a few or many more uncontrolled microorganisms harboring in nature's hidden ecosystem and its reservoirs? The answer is "yes"; there may be more, and thus we need to regularly monitor our environment, which directly or indirectly affects our health.

Among the various spheres (air, land, and water), a vast area on our earth is covered by water, dwelled by *n*th number of aquatic flora and fauna. Our oceans are hidden reservoirs of innumerable drugs we use today, whether it is to treat AIDS, Ebola Virus Disease (EVD), cancer, inflammation, nerve damage, Severe Acute Respiratory Syndrome (SARS), and maybe for corona virus too (Singh et al. 2020; Blasiak et al. 2020). The antiviral properties are essential in the sulfated polysaccharides found in bacteria and many algae. Thus, the solution to situations that threaten mankind in a condition like this is present in the hidden reservoirs of deep ocean beds.

The lesson to be taken from Covid-19 is to look around what is hibernating our environment, which may mushroom all of a sudden. These co-habitants may be biological agents like microbes, bacteria, viruses, animals, plants, and algae unexplored, thriving alone or in phycosphere assemblages in our marine and fresh water life, bringing silent changes in our environment with time. Recent news related to Covid-19 on the UNESCO website (https://en.unesco.org/news/covid-19-ocean-ally-against-virus-0) quotes, "*The marine environment is very rich from the point of view of biodiversity and resources useful for humans' daily life are still to be discovered*," said by Francesca Santoro IOC Project Office at the UNESCO Regional Bureau for Science and Culture in Europe (Venice, Italy), interviewed by Corriere della Sera's Quimamme, who explained that the "*ocean is an ally in fighting the virus. Not only does it help in the detection of COVID-19 but also combat it.*" *The ocean is closely tied to human health. Our ocean and coasts affect us—even those of us who don't live near the shoreline.*

Not only oceans but even our fresh water bodies affect the environment we live in. The primary producers of our water bodies are phytoplankton, which are reservoirs of immense diverse metabolites (Moran and Durham 2019). Among these, diatoms constitute the major density and diversity, contributing 35–75% to oceans (Nelson et al. 1995; Smayda 2011). However, they may be found solitary or in assemblages with other microorganisms in their phycosphere. The interactions among various diatoms and other microorganisms like bacteria (Cole 1982), viruses (Tomaru et al. 2012), fungi (Canter and Lund 1953), and anthropogenic and natural factors may be symbiotic or harmful to their growth. Therefore, it is necessary to understand the diatom assemblages, the ecological succession, harmful diatom blooms, metabolites produced, and the effect of the environment and anthropogenicity-induced teratological and phenotypic plasticity in diatoms. Since diatoms are particularly known for their rigid silica wall, they are typically *silica in glass houses*, incorporated with hydrated silica ($SiO_2{\cdot}nH_2O$) (Gordon et al. 2009). They can tolerate robust anthropogenic environments, thus useful in monitoring the quality of water (Losic et al. 2009). Besides this, the dead fossilized diatoms are useful tools to determine the environmental conditions in the fossilized era (Hassan et al. 2008). There are about 200,000 species of diatoms worldwide having different shapes, sizes, and metabolites as per the environmental and nutritional distribution (Guiry 2012). Therefore any change in the physical and environmental parameters results in a change in their morphology and physiology (Winder et al. 2008; Sun et al. 2011). Thus, they act as environmental indicators, and under conditions of stress, their cell density, lipid content, and even morphology are affected (Falasco et al. 2009; Roessler 1988; Round et al. 2007).

The changes in diatom community composition are also affected by environmental stress, especially carbon dioxide. Diatoms are responsible for fixing one-third of atmospheric carbon dioxide and responsible for releasing about 20–50% of oxygen we inhale. Any change in the diatom community can reorganize the flux of carbon in the food web in the aquatic ecosystem (Armbrust 2009). The organic carbon sequestration in the deep ocean in 1989 was 1.8 times higher when North Atlantic spring bloomed and was dominated by large species compared to smaller species in the following year (Boyd and Newton 1995). Likewise, larger diatoms were responsible for the transfer of efficient primary production to higher trophic levels due to less trophic intermediates involved. The ocean acidification in subtropics can bring change in the diatom community by an increase in diatom biomass. This was studied in a lab simulated experiment where a high CO_2 level (~620 μatm) in a diatom community sized ~8 m^3 volume for a month resulted in an increase in differential growth rates in different diatoms (Bach et al. 2019). This altogether altered the carbon composition of larger diatoms like *Guinardia* in the community, which resulted in an assemblage shift after nutrient fertilization with the highest carbon content. This has also been explained via the negative CO_2 effect on copepods grazing on diatoms. The high CO_2 and hence low pH reduce the growth and grazing of copepods, thus reducing their abundance and grazing pressure on diatoms (Bach et al. 2019).

16.3 Status in Terms of Number and Diversity Indices

The biodiversity of diatom species in marine as well as fresh water is important to know the diatoms databases and its diversity in different regions and seasons. Since diatoms are photosynthetic, they synthesize food in the form of carotenoids, specially fucoxanthin and lipids. They are important crude oil reservoirs, and geologists believe that 30% of the world's crude oil comes from diatoms (Krebs et al. 2010). On the other set, agriculturalists believe that diatoms make ten times more oil per hectare than the oil seeds (Hu et al. 2008), with theoretically calculated values reaching 200 times (Sheehan et al. 1998; Hu et al. 2008). Although all diatoms contain oil and antioxidant-rich metabolites, we need to select and screen oil-rich strains for commercial production. Besides this, diatoms are excellent water indicators as their morphological structure changes with a change in the environmental or anthropogenic pollution in the water. This may bring diatom blooms, which may or may not be harmful not only for their own phycosphere but also for the ecology of water in which they are thriving.

"The diatom *Didymosphenia geminata* (Bacillariophyceae) has garnered increased attention as a nuisance and invasive species in freshwater systems. Historically described as rare yet cosmopolitan, a suspected new variant of *D. geminata* has the capacity to inundate kilometers of river bottom during a bloom. Unlike most other bloom-forming algae, *D. geminata* proliferates under high water quality (i.e. low turbidity and low nutrient) conditions" (Kirkwood et al. 2007).

Environmental conditions including warming, salinity, nutrient supply, and grazing pressure play an important role in diatom cell size, motility, coloniality, etc. Long-term datasets (1900–2015) of diatom morphology and cell size clearly show that mean cell sizes of diatoms in Laurentian Great lakes have decreased with time, which may be attributed to climate change (Bramburger et al. 2017). In the case of benthic diatoms from the Baltic Sea, warming and reduced salinity resulted in smaller cell size while increased nutrient supply in warm conditions supported the production of larger sized diatoms (Svensson et al. 2014). According to a study by NASA, the population of the largest phytoplankton, i.e., diatoms, has declined from 1998 to 2012. There is a fall in diatom population over 15 years of the study period as the mixed layer becomes shallower, resulting in fewer nutrients reaching diatoms. This results into population decline, thus reducing the carbon dioxide drawn from the atmosphere and transferred into Deep Ocean. *Source:* NASA's Goddard Space Flight Center (https://svs.gsfc.nasa.gov/11934).

16.3.1 Diatom Biodiversity in Indian Subcontinent

India, also known as the land of rising suns, is the seventh large country, with 9% of its area occupied by water. It is a country with multiple weather conditions experiencing winter (January–February), summer (March–May), a monsoon (rainy) season (June–September), and a post-monsoon period (October–December) in bloom. In India, diatoms were intensely studied by Hemendrakuma Prithviraj Gandhi (1920–2008). He is probably known as the Father of Indian fresh water diatoms. He discovered about 300 new species from the Indian subcontinent; some of them were endemic to the Western Ghats. He had two diatom species known after him: *Eunotia gandhii* P.T. Sarode & N.D. Kamat and *Navicula gandhii* Meister (Karthick 2009). The expanse of diatom diversity in the Indian subcontinent extends from freshwater systems like lakes and rivers to the marine environments, including Arabian Sea, Bay of Bengal, and Central Indian Ocean.

16.3.1.1 Freshwater Systems

We studied the biodiversity from about 21 fresh water bodies of North India, Haryana, located at between 27°39′ and 30°35′ N latitude and between 74°28′ and

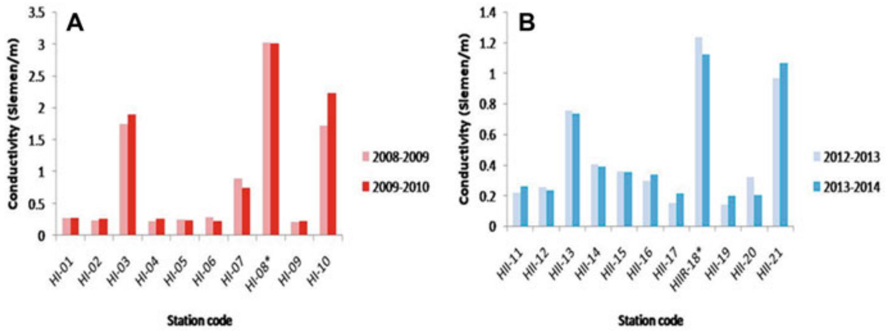

Fig. 16.1 Conductivity of water collected from ten water sites in Haryana during the (**a**) first-year (2008–2010) and (**b**) second-year (2012–2014) of investigation

77°36′ E longitude for 2008–2014. This study circled ten water bodies of Haryana during our first-year investigation, which included sites like Western Eastern Yamuna canal, Panipat (HI-1), Western Eastern Yamuna canal, Karnal (HI-2) Pond, Ambala (HI-3), Brahmsarover Lake, Kurukshetra (HI-4), Rani Lake, Jind (HI-5) Bhakra Canal, Hisar (HI-6) Pond, Mewat (HI-7), Bhaghot Pond, Mahendragarh (HI-8*), Tilyar Lake, Rohtak (HI-9) Pond, and Bhiwani (HI-10). Among the various water bodies investigated for the presence of a variety of diatoms, it was found that Bhagot Pond of Mahendergarh shows distinct features. It is situated north latitude 27°47′ to 28°26′ and east longitude 75°56′ to 76°51′ of Haryana, India. The conductivity at Baghot pond of Mahendergarh (HI-8*) was significantly high (~3.0 Siemens/m) compared to the rest of the water sites (~0.25 Siemens/m) except in HI-10, which was ~2.0 Siemens/m as seen in Fig. 16.1a. The very interesting feature of this finding was the dominance and endemic nature of centric diatom *Cyclotella meneghiniana* in this water site.

In our second investigation during the year 2012–2014, another set of 11 water sites of Haryana, India, were analyzed, including the repeat of site Baghot pond, Baghot, Mahendragrah (HI-8*) due to its distinct feature of showing the dominance of only one centric diatoms. These 11 sites were Karna Lake, Karnal (HII-11), Sannhit Lake, Kurukshtra (HII-12), Saraswati River, Pehowa, Kurukshetra (HII-13), Tikkartaal/Pond, Morni Hills, Panchkula (HII-14), Yamuna River, Karnal (HII-15), Sultanpur Lake, Gurgoan (HII-16), Yamuna River, Yamuna Nagar (HII-17), Baghot pond, Baghot, Mahendragrah (HII-18*), Damdama Lake, Gurgoan (HII-19), Markanda River, Ambala (Seasonal river) (HII-20), and Ghaggar River, Cheeka, Kaithal (HII-21). Apparently, there was a fall in the conductivity values for site HII-18*, and this time it was on an average ~1.00 Siemens/m than the rest of the water bodies (0.35 Siemens/m), as seen in Fig. 16.1b. The salinity of HII-18* felt halfway from ~3.0 Siemens/m during our first investigation to ~1.0 Siemens/m in the second investigation. It is well known that diatoms are found in saline and alkaline saline lakes. Salinity may have an indirect effect on the thickness of the diatom’s silica wall as well as its distribution and pore size. An increase in salinity

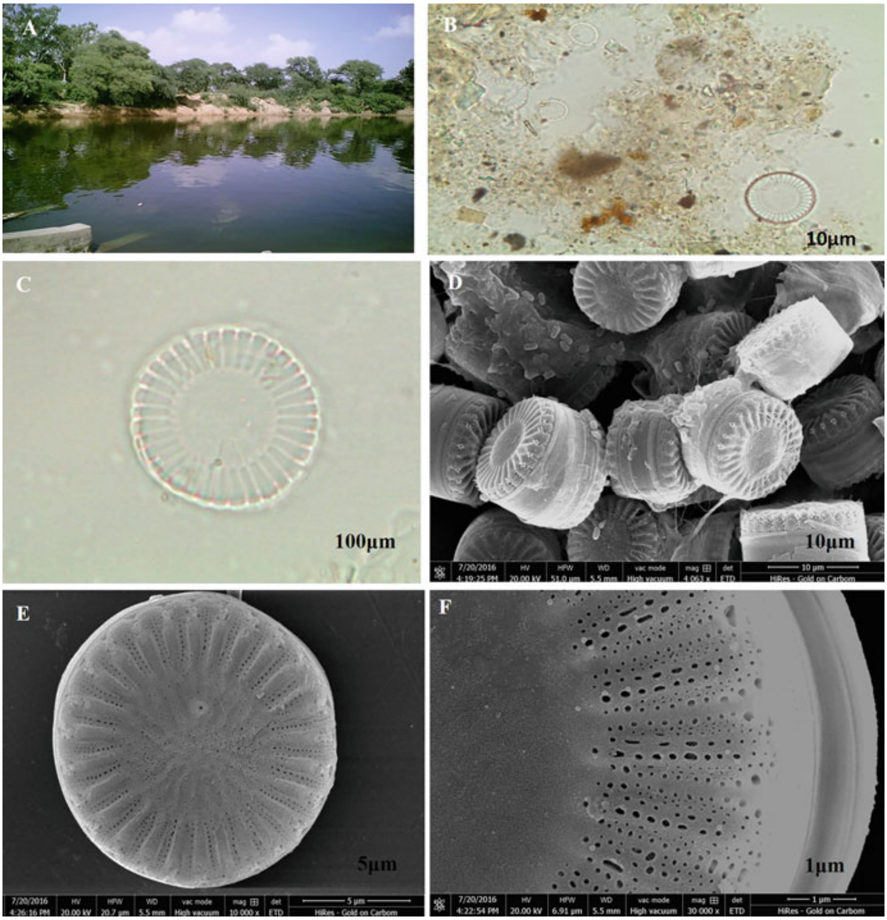

Fig. 16.2 (**a**) Bhaghot pond, Mahendergarh, Haryana, showing dominance and epidemic presence of *Cyclotella menenghinianana*. (**b**, **c**) Optical images. (**d**, **e**) SEM image and (**f**) SEM image showing pores

decreases the pore size, thus influencing the nutrient transport across cell membranes affecting cells' physiology and valve morphology.

The most important feature at Baghot pond, Baghot, Mahendragrah (HII-18*) (Fig. 16.2a) during second-year study again was the same as observed in our earlier investigation, i.e., endemic and dominance nature of centric diatom *Cyclotella meneghiniana* as seen in Fig. 16.2b, c. It is noteworthy this time that even though centric diatom *Cyclotella meneghiniana* was dominant, other diatom species were also found such as *Fragilaria capucina* (Desmazieres), *Tabularia fasciculate* (Agardh), and *Hantzschia virgata* (Roper) and *Coscinodiscus eccentric* (Grunow) was rarely found.

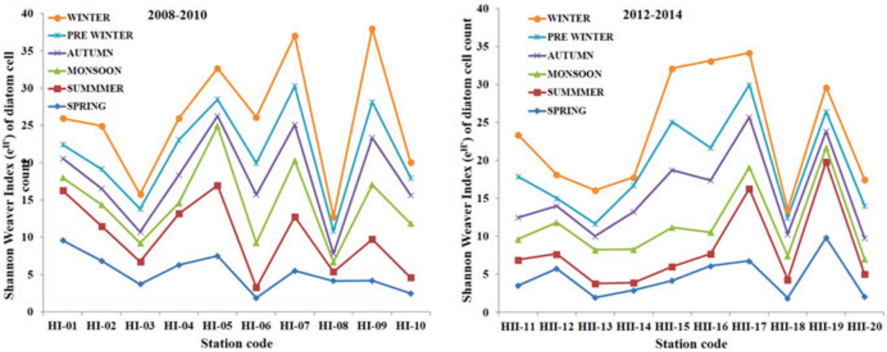

Fig. 16.3 Average of the Shannon weaver index in relative diatom abundance for 2008–2010 and 2012–2014

Cyclotella meneghiniana (Kützing) is a fresh water species, which is drum-shaped with tangential undulations; less frequently, the valve face is flat (Fig. 16.2d–f). Valves 10–40 μm in diameter marginal zone with strongly radial striae, 8–9/10 μm, broader at the margin and tapering toward the center. Valve center unornamented, except for a few, small, central strutted processes.

However, there were changes in diatom cell density and relative abundance calculated by the Shannon weaver index during these two sets of investigations (2008–2010 and 2012–2014). Figure 16.3 shows average relative diatom abundance for 2008–2010 and 2012–2014, which is seen higher in winters, the most appropriate temperature condition for diatoms. A common pattern of ascending diatom cell abundance with season was examined as spring>summer>monsoon>autumn>pre-winter and winters. Diatoms thrive best in temperatures ranging between 18 and 22 °C, which is an ideal temperature in winters; thus, they show high cell abundance in winters (Zhao et al. 2014). Even though all sites followed a similar seasonal pattern, sites HI-05, HI-07, and HI-09 showed comparatively higher diatom cell density during the first investigation and HII-15, HII-16, HII-17, and HII-19 during the second investigation.

This in turn depends upon environmental and geographical location and thus helps in monitoring the water quality and its ecology. A total of about 56 diatom genera and 112 diatom species were reported in the first investigation during 2008–2010 (Vandana 2012). However, a total of 52 different diatom genera were commonly found; 276 species of diatoms were observed in 2012–2013, and 265 species of diatoms were observed in 2013–2014 in 11 selected water bodies of Haryana. Among them, 46 genera belong to the Pennale order and 6 genera belong to the Centrale order. The results were in concordance with our earlier work (Vandana 2012) on change in diatom cell density with the season.

During these investigations, the maximum number of diatoms belonged to order Pennales in the order of *Gomphonema>Navicula>Nitzschia*. While the least

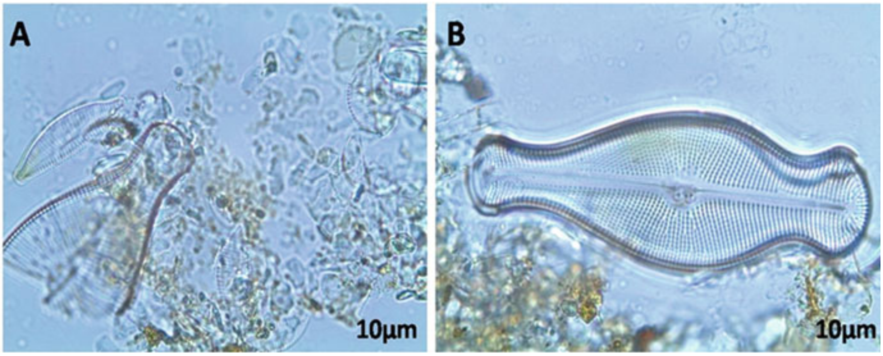

Fig. 16.4 *Didmyosphenia geminata* from a water sample of Shopian River, Jammu and Kashmir, India. (**a**) In a mixed population with *Cymbella* and (**b**) *Didmyosphenia geminata*

occurring diatoms of this order Pennale were *Karayevia clevei*, *Opephora pacifica*, *Rhoicosphenia* sp., *Staurosirella pinnata*, and *Stenopterobia densestriata.*

In order centrales, highest numbers of species observed were that of *Cyclotella* while least occurring diatoms of this order were *Pleurosira* sp. and *Stephanodiscus* sp. This is the first study for these water bodies; however, some workers have also studied Tikkar tal/Pond, Panchkula (HII-04) from December 2013 to September 2014 and reported eight diatoms, namely *Achnanthes*, *Cyclotella*, *Gomphonema*, *Hantzschia*, *Navicula*, *Nitzschia*, *Pseudostaurosira*, and *Stauroneis* (Saini et al. 2017). However, our study during these two consecutive years 2012–2014 at the site Tikkar tal/Pond Haryana (HII-04) showed the presence of *Achnanthes* sp., *Achnanthidium* sp., *Amphora* sp., *Aulacoseira* sp., *Brachysira* sp., *Caloneis* sp., *Catenula* sp., *Cocconeis* sp., *Craticula* sp., *Cyclotella* sp., *Cymbella* sp., *Cymbopleura* sp., *Denticula* sp., *Fragilaria* sp., *Gomphonema* sp., *Gyrosigma* sp., *Hantzschia* sp., *Luticola* sp., *Mastogloia* sp., *Navicula* sp., *Neidium* sp., *Nitzschia* sp., *Pinnularia* sp., *Placoneis* sp., *Rhoicosphenia* sp., *Rhopalodia* sp., *Sellaphora* sp., *Staurosirella* sp., *Surirella* sp., *Synedra* sp., *Tabularia* sp., and *Tryblionella* sp.

We did not observe any invasive species in Haryana or other sites that are under investigation to date in higher Himalayas (Ladakh), South India (Kottayam), and Northeast (Shillong, Sikkim). However, on examining and reporting a drowning case in the State Forensic Science Laboratory of Jammu and Kashmir in 2009, an invasive species of diatom was observed in the Shopian river of Jammu and Kashmir identified as *Didmyosphenia geminata*, as seen in Fig. 16.4. It has been claimed that *Didmyosphenia geminate* is an indication of environmental change (Kawecka and Sanecki 2003). Unlike cyanobacteria and chlorophytes that form blooms, *D. geminata* blooms do not occur under eutrophic conditions. They are cosmopolitan yet rare lotic species found in cold flowing streams without requiring any elevated nutrient or poor water quality. In India, they were first reported in 2003 and 2004 Kishanganga and Ravi rivers of the Western Himalaya and from Teesta river and its two tributaries in the Eastern Himalaya (Bhatt et al. 2008). This diatom has attracted much attention due to its negative effects on fresh water biodiversity.

D. geminata blooms may increase the overall invertebrate population and decrease EPT (E = Ephemeroptera, P = Plecoptera, T = Tricoptera) abundance (Larned and Kilroy 2014). The cells of *Didmyosphenia* possess a raphe-like structure, which allows them to glide on surfaces. They also possess an apical pore field, which allows them to attach to rocks, plants, and debris. During asexual reproduction, as the cell divides, the stalk also divides, forming a dense mass of branching stalks. Basically, it is not the cells of these diatoms responsible for nuisance but the immense stalk. The mat formed by the stalks changes the ecology of the streams with concern to species, diversity, low nutrients, low dissolved oxygen, and population niche for different species (Larned et al. 2006). The earliest report of *D. geminata* was reported in Northern America on Vancouver Island, British Columbia (Cleve 1894–1896) (Spaulding and Elwell 2007). Nearly after 100 years, its bloom was found in Heber River and within 5 years it spread to nearly 12 watersheds of Vancouver Island (Spaulding and Elwell 2007). The worldwide distribution of *D. geminata* is shown in Fig. 16.4c (Spaulding and Elwell 2007).

In India, the study of this nuisance bloom is limited and needs attention before it lays any harmful effect on our aquatic ecosystem.

16.3.1.2 Marine Environments

Although the diversity of phytoplankton, specifically diatoms in the marine waters around the Indian peninsula, dates back to more than 70 years, the real thrust in understanding the diatom population diversity came with the initiation of the International Indian Ocean Expedition (IIOE) from 1959 to 1965 under the aegis of Scientific Committee on Ocean Research (SCOR). A series of expeditions during this period in the Arabian Sea, Bay of Bengal, and the Central Indian Ocean under this multinational initiative resulted in the development of an Oceanographic Atlas for the Indian Ocean (SCOR-IOC/UNESCO). Since then, the diversity of diatoms and other phytoplankton groups have been studied under various international programs, including Joint Global Flux Studies (JGOFS), Bay of Bengal Process Studies (BoBPS), Cobalt Crust (CoCrust), IndoBiS, etc.

The entire Indian Ocean waters surrounding the Indian Peninsula can be categorized into the coastal, shelf, and open ocean regions. The diatom diversity and population in these waters are influenced both spatially and seasonally due to nutrient limitation/availability, growth conditions (temperature and salinity), and grazing pressure (Devassy and Bhattathiri 1974; Devassy and Goes 1989; Paul et al. 2007; D'costa and Anil 2010). For example, diatoms are the predominant group of phytoplankton in the Arabian Sea (AS), which included *Nitzschia longissima*, *Nitzschia seriata*, *Thallasiothrix* sp., *Leptocylindrus* sp., *Chaetoceros* sp., *Rhizosolenia* sp., *Guinardia* sp., *Lauderia* sp., etc., of which many are found only in summer (Sawant and Madhupratap 1996). The important factors controlling the seasonal variability in the AS are the monsoon upwelling and grazing by zooplankton. Diatom population in the northern Arabian Sea is largely dominated by cells of *Rhizosolenia*, *Chaetoceros*, *Biddulphia*, *Coscinodiscus*, and *Navicula* sp., in response to the hydrographic changes in summer monsoon (Parab et al. 2006). Tarran et al. (Tarran et al. 1999) showed that diatom diversity was highest during summer monsoon than in inter-monsoon and was largely influenced by coastal upwelling (Schiebel et al. 2004). In the Bay of Bengal, the distribution of diatoms also showed distinct seasonality. The predominant diatoms of the Bay of Bengal included *Thallasiothrix longissima*, *Thallasiothrix fauenfeldii*, *Rhizosolenia styliformis*, *Chaetoceros eibenii*, *Coscinodiscus radiatus*, *Coscinodiscus concinnus*, *Chaetoceros coarctatus*, *Nitzschia angularis*, *Skeletonema costatum*, and *Thallasionema nitzschoides* and contributed more than 2% of the total phytoplankton population (Paul et al. 2007). Unlike AS, diatom community in the Bay of Bengal is influenced by salinity in the shelf waters of the Hooghly river and by nutrient availability in the open ocean stations. Moreover, low N:Si (<1) and Si:P ratios (>3) indicate silica enrichment and rapid utilization of nutrients in the Bay of Bengal (BoB), resulting in a greater abundance of diatoms. The dominance of pennales over centrale forms of diatoms was influenced by nutrient ratios, while centrales were influenced by light availability, salinity, stratification, etc. (Paul et al. 2008).

In the coastal waters and continental shelf, the diversity of diatoms in AS and BoB were influenced by different parameters. In AS, Banse et al. (2014) highlighted the importance of nutrient injection in southwestern coastal waters due to monsoon upwelling, which supports blooms of diatoms. Some of the major species reported in coastal waters include cells of *Nitzschia*, *Navicula*, *Coscinodiscus*, *Rhizosolenia*, *Pleurosigma*, and *Licmophora* (Garg and Bhaskar 2000; Bhaskar et al. 2000). The seasonality of these diatoms was controlled by land run-off, nutrients, and grazers. In BoB, coastal diatoms were largely *Thallasiothrix*, *Skeletonema*, *Coscinodiscus* in the estuary (Baliarsingh et al. 2015), *Thallasionema*, *Dytilium*, *Odontella*, *Astreonella*, *Cyclotella*, and *Stephanodiscus* (Paul et al. 2008; Mishra et al. 2006).

16.4 Challenges

Both freshwater and marine ecosystems are exploited for transportation, fishing and aquaculture, trade, commerce, leisure and tourism, and industrial purposes. In addition to these activities, these ecosystems serve as a watershed for industrial and domestic effluents. The rapid global warming and the associated increase in surface water temperatures further alter the growth conditions. As a result, the frequency of toxic phytoplankton blooms is on the rise globally (Hennon and Dyhrman 2020). Various triggers include eutrophication and species competition (Roelke and Buyukates 2001), selective predation (Chakraborty and Feudel 2014), changes in pH (acidification) (Riebesell et al. 2018), iron availability (Wells and Mayer 1991), and extreme ocean warming events accompanied with strong stratification and deep thermocline (Du et al. 2016).

Among algal blooms, diatom bloom and its associated pathogenicity are less explored. It is noteworthy that the ecological significance of pathogens associated with diatom bloom in aquatic ecosystems (fresh water and marine) determines its health. Pathogens associated with phytoplanktons are generally not focused unless they emerge out to be a reason for the sudden change in the flora and fauna of that aquatic system. Most of the algal communities found in fresh water have hidden viral and bacterial infections.

16.4.1 Diatoms and Bacteria

The marine phytoplankton contributes 46% of the net primary production (Behrenfeld et al. 2001), of which diatoms alone contribute a major portion of global primary production (Caffrey et al. 1998). This represents an important source of dissolved organic carbon (DOC), which is a major food resource for heterotrophic bacteria living in phycosphere of diatoms. Diatoms, together in conjunction with phytoplankton, contribute to half of the total CO_2 of the earth (Christopher et al. 1998). It secretes exopolymeric substances (EPS), which makes it a reservoir of carbon and other nutrients cycling in the ocean. They have a phycosphere of microorganisms, especially bacteria that derive nutrition from it. The bacteria co-inhabiting diatoms further secrete exo-polysaccharides (EPS), accelerating the flocculation and changing their chemical composition. Aggregation plays an important role in the end of diatom bloom (Park et al. 2015, 2010). Aggregation of diatoms is influenced by the chemistry of the EPS secreted and get varyingly influenced by transparent exopolymeric particles (TEPs) and Coomassie-stained particles (CSP) (Bhaskar et al. 2005). The diatom–bacterial association can be purely symbiotic or parasitic, including those which feed on dead diatoms (Grossart et al. 2005). Oceanic bacteria need carbon and other nutrients, which are constantly provided by diatoms through which more than half of organic carbon produced by diatoms flows through bacteria. However, it is important here to note that diatom–bacterial interactions are unlike land plants and mycorrhizal fungi, which do not promote photosynthesis (Schweiger et al. 2014). However, both are benefitted from nutrients like vitamins, amino acids, and siderophores required for their growth (Amin et al. 2009). Clarke et al. studied the phycosphere around diatom *Skeltetonema marinoi* (Clarke et al. 2019) and found about seven different types of bacteria (*Antarctobacter heliothermus*, *Arenibacter algicola*, *Yooniavestfoldensis*, *Marinobacter salarius*, *Roseovarius mucosus*, *Sphingorhabdus flavimaris*, *Sulfitobacter pseudonitzschiae*). *A. heliothermus* and *Marinobacter salarius* stimulated the growth of *S. marinoi* maximum up to 24–48 h at certain fixed ratio with diatoms. *Marinobacter* has been studied to establish decade-old cultures of diatoms such as *Skeletonoma costatum*, *Phaeodactylum tricornutum*, and *Thallassiosira pseudonana* (Zecher et al. 2015). The *Marinobacter* affects the growth rate differentially, like it enhances growth rate in *T. pseudonana* and *S. marinoi* but decreases in *S. costatum.* Bacteria produce certain growth-promoting hormones like indole-3-acetic acid and some related compounds in the phycosphere of diatom (Amin et al. 2015). However, no other growth hormone or its precursor is responsible to enhance its growth as revealed by its genome. The genome of *S. marinoi* does reveal certain enzymes involved in indole acetic acid (IAA) synthesis. However, there was a lack of stimulation of growth for *S. marinoi* by these bacteria in the presence of red light. This is due to the fact that red light allows minimum absorption of light resulting into minimum photosynthesis. Besides this, the environment and nutrients play a crucial role in diatom–bacteria interactions. The major nutrients required for diatom growth are nitrogen, phosphorus, silica, certain vitamins, and traces of iron. The soluble iron is inadequate in oceans and is a limited growth factor for phytoplankton (Martin and Gordon 1988). Certain bacteria produce iron chelating agents known as siderophores (Sinha and Parli 2020; Sinha et al. 2019). Interestingly, genes that code siderophores are present in *Marinobacter salaries* and *Sulfitobacter pseudonitzschiae* (Töpel et al. 2019). It was seen that under low iron concentration, diatom *S. marinoi* was able to survive in the presence of bacteria *S. pseudonitzschiae* and *Y. vestfoldensis* even though no such gene coding for siderophore is observed in the latter (Clarke et al. 2019). However, there was no further enhancement in the growth of *S. marinoi* co-cultured with *M. salarius*. Temperature too is an important parameter for diatom growth, and a change in seasonal temperature in the benthic zone of diatoms at a temperature near 8 °C showed stimulation in the growth in the presence of bacteria; however, no change was noticed at higher (24 °C) or standard (16 °C) temperature for their growth. Culture-based studies of *Skeletone macostatum* showed that diatom-associated bacteria belonged to the Bacteriodetes phylum while free living bacteria belonged to the Roseobacter group of a-Proteobacteria, suggesting that diverse groups associated with diatoms may play an important role in organic carbon utilization (Grossart et al. 2005).

Bacteria can cause lysis of marine as well as freshwater diatoms. On April 16, 1988, Stewart observed hundreds of gray circular periphyton patches in the pools and riffles over 1+ km area of Brier Creek in south-central Oklahoma (Stewart 1988). These patches were gray and senescent and had a major population of diatoms, notably *Synedra ulna*. The cause of the occurrence of these patches was probably a pathogenic colonial community (fungi, bacteria, or viruses) that propagated from cell to cell. There were no hyphal bodies and the plaques from bacteria and virus colonies lysing diatoms, which was revealed in studies by researchers during that time (Reynolds 1984; Daft et al. 1975). It therefore suggested that waterborne pathogenicity was caused probably by bacteria or viruses. In yet another study, benthic bacterial community spread in diatom-dominated benthic community during late winter (February) and early spring (April) in Sonoran desert (Peterson et al. 1993). The ring-like patches of senescent diatom blooms spread from central areas as the infection spread at an area of a 5-km stretch. The diatom samples taken from the patchy areas showed dead diatoms with broken or no chloroplast compared to the diatom cells outside them. Transmission electron microscopy revealed no viral particles but invasive bacteria species without any evidence of fungal pathogenicity. The dominant diatoms during these two periods of infections were *Nitzschia linearis* and *Synedra acus* in February (~40% of total community), whereas they were *Nitzschia acicularis* and *N. palea* in April (~48% of total community). It was also observed that with the advent of bacterial infection, some diatom species decreased while some small adnate mucilage producing taxa like *Achnanthes minutissima*, *Amphora perpusilla*, *Navicula tantula*, and *Navicula crjptocephala* var. *zreneta* increased after infection, which alters the carbon fixation rates (Steinman et al. 1992). In this study during February and April, it was noticed that diatom densities increased in April concurrent with initial pockets of senescent growing pathogenicity in diatoms. It was concluded that bacterial pathogenicity was related to host density, which becomes more prevalent once host reaches a particular population density. Even though the infection during February was sustained, there were certain regions that did not show infection but silently lay until the density of diatom communities crossed a certain threshold. There are many reasons for this, of which the physical environment, physical condition of host cells, and nutrient availability play an important role (Peterson et al. 1993).

The period from 1980 to 1990 demonstrated that bacterioplanktons consume 30–60% of the organic carbon produced in phytoplanktons (Cole et al. 1988). Grazing by bacteria and viruses certainly leads to the consumption of resources needed by diatoms for their own physiology and metabolism, although diatoms derive Vitamin B12 from bacteria in cases where this association is symbiotic. It is assumed that there is a passive exchange of metabolites between the two depending upon the circumstances and availability of macro- and micronutrients. Researchers have shown that bacteria produce heat-labile substances that kill algae (Harris 1970; Mearns-Spragg et al. 1998; Ingram and Prescott 1954; Gorham 1964; Sakata et al. 2011; Shi et al. 2013; Kang et al. 2008; Oh et al. 2011; Kim et al. 2009; Wang et al. 2020; Xuan et al. 2017; Sun et al. 2018; Yu et al. 2018). The studies demonstrated the association of *Roseobacter* and *Cryptophaga* with phytoplanktons. The algicidal activity of associated bacteria may be due to the release of (1) soluble toxins by bacteria during growth, (2) diffusion of algicidal compounds across phytoplankton cell wall (in marine snow), and (3) releasing algicidal enzymes (Mayali and Azam 2004). Due to vast and variable genetic diversities in bacterioplanktons, their lineages are not distinct. Morris et al. (2006) used molecular and fluorescence in situ hybridization (FISH) techniques to localize the response of bacterioplankton to diatom bloom and non-bloom assembly in the Oregon coast. They found an association of *Pirellula* and *OM43* as dominant bacterioplankton in diatom blooms. Although there is no direct association with why these bacterioplanktons interfere with diatom metabolism, it has been seen that the molecular genome of *Pirellula* sp. strain 1 (*Rodopirellula baltica*) derives their energy from extra polysaccharides produced by algae (Glöckner et al. 2003; Schlesner et al. 2004) and in this case by diatoms (Nur et al. 2019). The lineages enumerated by FISH (DAPI-stained particles) showed that *Pirellula* sp. were cocci about 1 μm in contrast to rod-shaped OM43, whose cell density increased in diatom blooms. There indeed occur complex interactions between diatoms and bacteria.

Bacterial association with diatoms can also play an important role in the production of phytotoxins. Some bacteria are reported to produce the same toxin attributed to the microalgal symbiont host. For example, domoic acid (DA) is a phytotoxin produced by *Pseudo-nitzschia pungens*. Studies show that bacteria associated with this diatom enable the diatom to produce DA 8 to 38 times more than the axenic isolates. Also, the yield of DA varied with the diatom and bacterial strains. Bates et al. (1995) show that bacterial isolate associated with *Chaetoceros* enables cells of *Pseudo-nitzschia* to produce DA almost 115 folds more than usual. Moreover, these bacteria did not produce DA by themselves but enhanced the toxicity of these diatoms (Doucette 1995). Interestingly, the bacteria associated with the diatom for DA production were either found in the phycosphere or endocytobiont of toxic diatom (Bates et al. 1995). Another important outcome of the bacterial–diatom association is the pathogenicity of the bacteria and the diatom acting as a vector. For example, *Vibrio cholerae* has been widely reported to be associated with diverse forms of diatoms including fouling diatoms in a biofilm (Khandeparker et al. 2014).

16.4.2 Diatoms and Virions

Unlike diatoms and bacterial interactions, which can be mutualistic or antagonistic, diatom and virus interactions are always fatalistic and hasten cell death in diatoms. Viruses are one of the more important reasons for the sudden termination of diatom blooms both in marine and freshwater environments (Nagasaki 2008). The virions come in a variety of morphologies, size (20–200 nm size), and genome size, and their numbers vary from a few millions to ten billion per liter in the marine environment (Fuhrman 1999; Brussaard et al. 1996). Although bacteriophages are prominent in any aquatic realm, recent studies show that viruses and virus-like particles (VLPs) have been associated with more than 50 genera of microalgae (Nagasaki 2008). Viruses infect the diatoms, multiply, and break out of host cells, causing a sudden crash of diatom blooms and resulting in the release of dissolved organic carbon (DOC), which can support the growth of bacteria (Bratbak et al. 1998). Therefore, viral infections are important for sustaining the supply of DOC to fuel the bacterial carbon demand, which in turn is a key in controlling the microbial loop in aquatic environments. Thus, viruses play a key role in controlling the algal and bacterial populations and play an important role in aquatic microbial processes.

Since the late twentieth century, numerous studies have been carried out to understand the distribution, variety, and role of viruses regarding the phytoplankton (Bergh et al. 1989; Bratbak et al. 1992; Nagasaki et al. 1995; Jacobsen et al. 1996). Various methods have been adopted to visualize and enumerate these viruses, including epifluorescent microscopy, flowcytometry, transmission electron microscopy (TEM), etc. (Brussaard et al. 2000; Larsen et al. 2001). Experimental studies show that viral abundance of diverse size classes increased after the initial proliferation of algal cells, clearly indicating a close link between the two groups (Larsen et al. 2001).

Diatoms are either pennales or centrales in morphology, and the bulk of the viruses identified infects the centrale type of diatoms. For example, *Skeletonemacostatum* has been shown to get infected by ScosV, a DNA virus

(Kim et al. 2015a). In a review, the diatom viruses that infect cells of *Rhizosoleniasetigara*, *Chaetocerossalsugineum*, and *Chaetocerosdebilis* are described. The RsRNAV infecting *Rhizosoleniasetigara* multiply in the cytoplasm only while CsNIV and CdebDNAV infecting bloom-forming cosmopolitan *Chaetoceros* sp. multiply in the nucleus (Nagasaki 2008). Similarly, viruses have been isolated and characterized from cultures of *Chaetocerossocialis* (Tomaru et al. 2009), *Chaetocerosdebilis* (Tomaru et al. 2008), *Chaetocerostenuissimus* (Shirai et al. 2008), etc. More recently, a virus infecting *Guinardiadelicatula* was reported from the western English Channel and was identified as GdelRNAV(Arsenieff et al. 2019). The first pennale associated virus was identified by Tomaru et al. (2012). They isolated a virus AglaRNAV that populated the cytoplasm of *Astreonellopsis glacialis* while another virus TnitDNAV infected the nucleus of *Thallasionema nizschoides*. The site of the viral multiplication within the host cells makes it extremely important agents for lateral gene transfer and metabolic rewiring of the host genome (Bidle and Vardi 2011).

The effectiveness of the viral infection is measured by the multiplication rate and burst size. The lytic cycle may vary from <12–48 h (Tomaru et al. 2008; Nagasaki et al. 2004), while the yield may vary from 55 infectious units per cell (Tomaru et al. 2008) to 10^4 infectious units per cell (Shirai et al. 2008). The lysis by viruses to 50% of the initial population size of the host is called CR_{50}. Studies show that environmental factors like temperature and salinity coupled with host–virus combinations can influence the lytic cycle and CR_{50} (Kimura and Tomaru 2017).

Another important factor that can alter the CR_{50} is the production of exudates or exo-polysaccharides (EPS) by diatoms. Diatom exudates are rich in carbohydrates and proteins and serve as a major source of carbon for heterotrophic bacteria. During bloom conditions, EPS production peaks during the stationary phase and coincides with depletion in nutrients (Bhaskar and Bhosle 2005). Production of labile EPS by diatoms can support up to 25% of bacterial production (Fogg 1983). Azam and Ammerman (1984) suggest that bacterial numbers increase in the region of exudates (phycosphere), and the slime layer or EPS produced by diatoms can support bacteria living in it (Bratbak and Thingstad 1985). However, viral clusters do not concentrate close to the host surface to avoid adsorption (Murray 1995). During the late stages of bloom, bacterial clusters are formed in the slime layer and not on the diatom surface (Bratbak and Thingstad 1985). High numbers of bacteriophages within the slime may reflect viricidal properties in the phycosphere bacterial community. Murray (1995) suggested that diatoms may produce EPS to attract bacteria, which have viricidal properties and flagellates, which can graze upon large viruses.

Not only bacterial but viruses too form an important part of the diatom phycosphere. Viruses are an important part of the aquatic system and directly affect the primary producers through their interactions with many phytoplankton. These interactions cause infection and lysis and thus help in controlling the bloom of pathogenic or harmful blooms. The RNA viruses have strong interactions with bacteria, which in turn have strong associations with algae. The interactions of viruses with diatoms and some blue-green algae show growth of viral communities in such associations, which directly affect the ecology of algal blooms. The study of viral metagenomics in a dinoflagellate, *Gymnodinium catenatum*, showed the presence of *Siphoviridae*, *Podoviridae*, *Myoviridae*, *Phycodnaviridae*, *Mimiviridae*, and *Microviridae* (Du et al. 2020). However, the succession of viral as well as the algal community was dependent upon temperature and nutrients. However, the algal bloom rates were strongly dependent upon the type of virions regulated with winner and killing hypothesis (Thingstad 2000). The lysis of algal blooms by virions is probably because of the carbohydrate-active enzymes genes (CAZymes) rich in glycoside hydrolase (GH) and glycosyl transferase (GT) in viruses that lyse the polysaccharide wall of algae. This further promotes viral infection and a decline in an algal bloom. Since diatoms constitute about 35–75% of primary production and transfer of carbon to consumers (Nelson et al. 1995), their density and species need to be monitored time and again. Diatoms thriving in nutrient-rich ecosystems have seasonal diversity of species and blooms in their phycosphere (Sommer et al. 2012). There are viral species that may be parasitic, pathogenic, or symbionts. Among viruses harboring in diatom's phycosphere, very little study has been done. The viruses found in diatoms are certain for their hosts, particularly with a specific species or even a strain. *Guinardia delicatula* diatom is a highly abundant diatom species forming its bloom in early summers and autumn in Western English Channel, WEC. Aresenieff et al. reported four ssRNA viruses causing lysis in diatom *Guinardia delicatula* for the first time (Arsenieff et al. 2019). To date, up to 20 viruses associated with diatoms have been studied, and this needs more study since virions associated with diatoms not only are responsible for their mortality but also bring environmental successions for the silent niche harboring in nature (Kimura and Tomaru 2017). These were new viruses belonging to the *Bacillarnavirus* genus, which when tested on uninfected cultures of *G. delicatula* caused their complete lysis named GdelRNAV. Further on cross-infecting 15 phytoplankton species (including *G. delicatula*) with these four viruses showed that *G. delicatula* was the only species lysed by them, showing them to be host specific (Arsenieff et al. 2019). Thus, in order to understand the vast metagenomic data in our environment, it is important to study the genomes of new viruses. The seasonal monitoring of Western English Channel proved that GdelRNAV is temperature dependent and more prominent in late summers. Hence, the diatom bloom rate of *G. delicatula* was less in this weather and high during spring and early summers. Besides regulating algal blooms, the integrated omics approach shows that there is variation in microbial and viral community in a diatom bloom along with emergence of new virus lineage, which may bring sudden mortality in its surrounding and succeeding ecosystem. It has been proposed that cell destruction by viruses is more hazardous than bacterivory. Studies at Antarctic waters have demonstrated that densities of viruses are directly related to chlorophyll concentration of bacteria and phytoplanktons, which bring more mortality than the prokaryotic grazers (Evans et al. 2017). A study to identify some viruses in diatom-dominated bloom in late summer during 2014 in Chile Bay, West Antarctic Peninsula (WAP), at low and high Chl-*a* content periods (LC and H-C) showed distinct viral compositions (Alarcón-Schumacher et al. 2019). The L-C sample showed the dominance of viruses from

Myoviridae, about 82% having order Caudovirales, which generally infects bacteria and archaea. This was followed by viruses from Phycodnaviridae (~9%) and Inoviridae of viruses (~8%) of the total viruses read in a frame. The meta-transcriptomic data however revealed ~54% of the Phycodnaviridae family in the L-C samples followed by 38% of the Myoviridae family along with 8% of ssRNA viruses. In the H-C sample, the viral community and its composition changed and here Phycodnaviridae from order Megavirales was dominant (~93%), whereas Caudovirales order disappeared and Myovirales showed only 3% of all viruses read and Siphoviridae increased to ~3.5% and Inovirus group almost disappeared (~1%). This showed different metagenomic composition of viral community in L-C and H-C samples during summertime. The eukaryotic phytoplanktons found in L-C samples was dominated by diatoms (Phylum Bacillariophyta; ~77%) of order Thalassiosirales (~67%) and Bacillariales (~10%) and rest of cryptophyes (~3%) and haptophytes (~5%). The H-C sample showed an increase in the relative abundance of diatoms to ~80% and haptophytes to ~11%. On assembling the metagenomes from L-C and H-C, it was found that complete set of genomes from PAL E4 and Pal 156 ssRNA virus were identified from the L-C and H-C samples with an overlapping single sequence of *Pseudo alteromonas* phage Chile Bay Antarctica. In addition, a new dominant viral group identified from the H-C sample as Phycodnavirus was named *Phycodnavirus Antarctica* virus, which has alignment with *Phaeocystis globosa* virus genome. This is predicted to kill blooming haptophyte *Phaeocystis antarctica* in the Southern Ocean. The prokaryotic community comprising of Gamma proteobacteria in summertime in both L-C and H-C samples was 71% and 76%, respectively. The dominant group in L-C was that of Pseudomonadales (~42%) followed by Flavobacteriales (~14%) and Bacillales (~11%). Whereas in the H-C samples Alteromonadales was 65% followed by Flavobacteria (~16%) and Rhodobacteriales (~5%). The phage community in Chile Bay WAP revealed novel *Pseudoalteromonas virus* (Pp CBA) whose whole genome showed 24% identity with *Pseudoalteromonas* phage H101 identified and isolated from the Yellow Sea China. The increase in *Pseudoaltermonas* in Chile Bay decreased the viral activity of *Pp CBA* virus in the chlorophyll-rich samples (H-C). In this study at Chile Bay, Thalassiosirales are the dominating diatoms, which serve as potential host for Bacillarnavirus. The studies have shown that both RNA and DNA viruses infect pinnate and centric diatoms, thus regulating the ocean's phytoplanktom bloom and carbon reserves in the food web (Alarcón-Schumacher et al. 2019). In our recent study on diatoms for biofuel, culturing them produces a variety of diatom strains, and in a recent study to identify diatoms, we found a spiked virion (unnamed) associated with diatom *Sellaphora*. Figure 16.5a shows the TEM image of spiked virion, which we had not seen earlier or probably missed it. With the recent attack of Covid-19, we want to highlight a virion unexpectedly observed in the diatom culture of *Sellaphora* species with its axial portion seen in Fig. 16.5b. Important thing to mention here is that there was instant lysing of *Sellaphora* sp. cultures in laboratory.

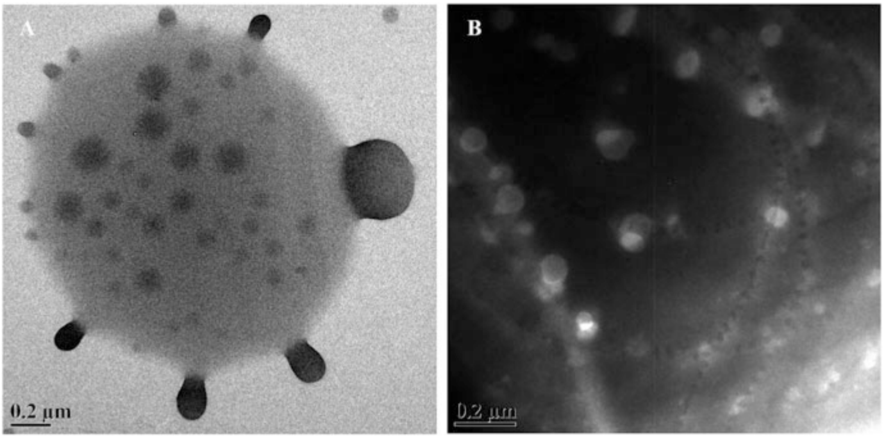

Fig. 16.5 (**a**) TEM image of a virion found associated with diatoms. (**b**) Axial portion of *Sellaphora* sp.

16.4.3 Diatoms and Fungi

Besides virions attacking the diatoms in their assemblages, there is another group of microorganisms associated, which are probably equally lethal for diatom growth. These are fungi, especially the chytrids. Chytrids are true fungi, whereas oomycetes are stramenopiles, a heterotrophic sister group in photosynthetic marine algae and diatoms (Gleason et al. 2011). Although fungi and related Opisthosporidia interact with photosynthetic land and water plants, there with diatom is less studied. One such novel chytrid-like clade (NCLC1) has been identified in marine samples of Europe (Richards et al. 2015). The unwanted pathogenicity may destroy whole algal blooms in the ocean or fresh water, which may invite a phytoplankton succession (Chambouvet et al. 2008; Lima-Mendez et al. 2015). Although diatoms are known to be abundant algae in marine ecosystems, very few research studies show any control of their parasitic or pathogenic blooms. Oomycetes parasites have control of the toxic bloom of some diatom species (Garvetto et al. 2018). However, the diversity of fungi in the marine environment has been scarcely studied. To investigate the NCLC1 life cycle in marine environment, the fluorescent in situ hybridization (FISH) technique was tested on samples collected from the site from where earlier NCLC1 harbored (Chambouvet et al. 2019). In the FISH technique, the counter staining of DNA was done using propidium iodide. The FISH analysis revealed that NCLC1 cells were associated with diatom surface showing an epibiotic association. The analysis showed that the diatoms were found abundantly both in water from the sub-surface (1-m depth) and deep chlorophyll maximum (DCM; 20-m depth) fractions with *Chaetoceros*, *Skeletonema*, and *Pseudo-nitzschia* and were homogeneously associated with NCLC1. This is quiet suggestive of the fact that NCLC1 is active in both pelagic and benthic waters. Also, it has to be noted that *Pseudo-nitzschia* is a toxic diatom bloom responsible for producing domoic acid. Domoic acid caused a large outbreak of shellfish poisoning in 1991. This shows the hidden or undetected association of diatom blooms of *Chaetoceros*, *Skeletonema*, and *Pseudo-nitzschia* in marine waters with fungus. However, diatom NCLC1 association is unknown but possibly reveals a parasitic, mutualistic, and saprophytic infection. Figure 16.6 shows NCLC1 infection on dead diatom cells lacking nuclei or nuclei being digested by NCLC1, confirming that host is dead (Chambouvet et al. 2019). Therefore, represented this interaction as necrotrophic parasitic interaction on these diatom carcasses. Not only NCLC1 but virions, protist and fungal pathogens, and chytrids play an important role in infecting and digesting diatom blooms.

In yet another study, the effect of such eukaryotic pathogens like chytridiomycetes and oomycetes has been studied on diatoms (Gutiérrez-Gutiérrez et al. 2013). In fact, the presence of a few chytrids like *Rhizophydium littoreum* Amon, *Thalassochytrium gracilariopsidis* Nyvall, Pedersén, and Longcore, *Chytridium polysiphoniae Cohn*, and *Dinomyces arenysensis* has been studied in the marine environment, but none have been studied with respect to diatoms. However, oomycetes are abundant in the marine environment and have been studied for their pathogenicity against diatoms (Sekimoto et al. 2008a, b; Sparrow 1969). The microphytobenthos forms are widely dispersed in intertidal areas. These form biofilms that are rich in diatom blooms having high cell density. The exopolysaccharides secreted from the diatoms in these blooms act as a high source of food for benthic and pelagic communities (Admiraal et al. 1984). This leads to ecological succession in diatom communities, which shows the relation to taxa and physical parameters for the proliference of the same (Scholz and Liebezeit 2012; Woelfel et al. 2007). A brief survey of the microphytobenthic community in summers of southern North Sea, Germany, revealed diatom cells infected with sporangia as the first evidence of eukaryotic parasites in benthic diatoms belonging to order *Naviculales* and *Achnanthale* (Scholz et al. 2014). Among the oomycetes, *Lagenisma coscinodisci* Drebes is described as an endobiotic parasite of centric diatom *Coscinodiscus centralis* (Drebes 1966, 1968; Gotelli 1971), and also endo-parasitic saprolegniaceous oomycete *Ectrogella zopf* as a parasite on diatom *Licomophora agardh* (Sparrow 1969). However, chytrid infections were most common on freshwater phtoplanktons, which were resistant to zooplanktons. It was seen that more than 90% of species in a population were infected by chytrids leading to the death of host cells by these fungi (Ibelings et al. 2004, 2011). The detection of these eukaryotic fungal parasites is difficult directly under a microscope and therefore needs fluorescein isothiocyanate (FITC) with CalcoFluor white (CW) and wheat germ agglutin (WGA) conjugate with a given sample observed under an epifluorescence microscope (Marano et al. 2012). The presence of multiple fungal parasitic infections in different diatom taxons suggests diatom succession in a community. Scholz et al. (2014) showed diatom infections by different types of chytrids in the southern North Sea, Germany intertidal community. The diatom taxa infected by oomycetes were those belonging to Bacillariales, Naviculales, Achnanthales, and Thalassiophysales.

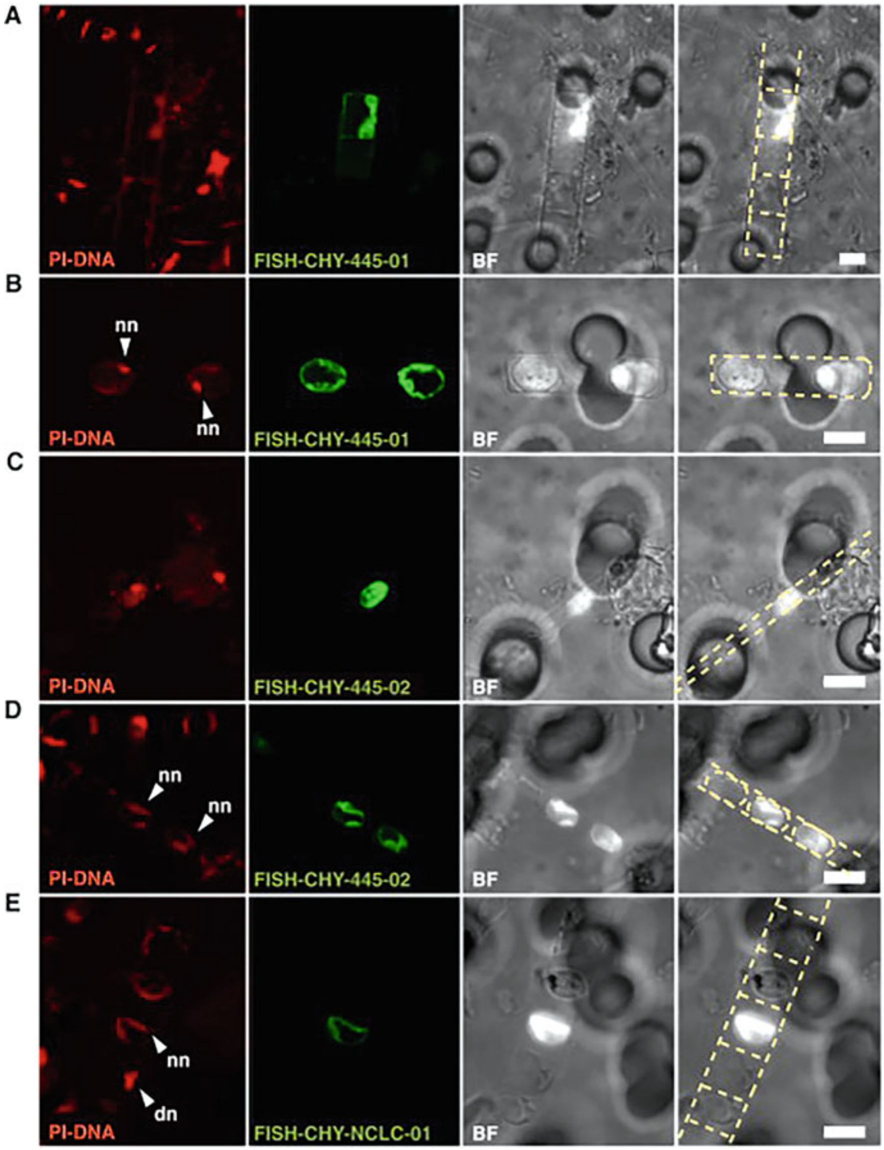

Fig. 16.6 FISH microscopy evidence for NCLC1 intracellular associations with diatom phytoplankton. (**a**) Intracellular infection of *Chaetoceros*-like diatoms, (**b**) infection of *Leptocylindrus*-like diatoms, (**c**) infection of *Pseudo-nitzschia*-like diatoms, (**d**) infection of *Skeletonema*-like diatoms, and (**e**) infection of *Chaetoceros*-like diatoms. Scale bars, 10 mm. PI corresponds to nuclear DNA staining with propidium iodide; green displays cells with a positive signal for the horseradish peroxidase (HRP) FISH-labeled probes, with the specific name of the probe included on each image. BF (bright-field) corresponds to the transmitted light with differential interference phase contrast. (Reproduced with permission from Chambouvet et al. (2019))

16.5 Reasons of Worry

16.5.1 Harmful Diatom Bloom

Harmful algal blooms are a threat to the health of our society; they have a constructive way for their occurrence in algal blooms, which may be harmful as they may change not only their own but their surrounding ecology as well. Since these microbes play a very crucial role in regulating the life cycle of algae by controlling their metabolism, absorbing essential nutrients, releasing nutrients stimulating their growth (Ferrier et al. 2002), lysing algae, autoregulating bacteria algae association (quorum sensing) (Zhou et al. 2016), inhibiting sexual reproduction (Sanders 2014), etc. The association of bacteria and virion with algae may make the algal blooms harmful not only for humans but also for animals.

16.5.2 Toxic Metabolites

16.5.2.1 Domoic Acid

Currently, the toxic domoic acid bloom of diatom is life threatening to both human and wildlife. Domoic acid (DA) is a naturally occurring amino acid initially isolated from red algae (*Chormdria armaia* and *Alsidium csraklinum*) (Fattorusso and Piattelli 2012). It is also present in diatoms isolated from *Nitzschia pungens* (Rao et al. 1988). A sudden case of the first human domoic acid toxicity occurred during 1987 in Prince Edward Island (P.E.I) Canada and is popularly known as Amnesic shellfish poisoning (ASP) (Bates et al. 1989). Its clinical symptoms include gastrointestinal distress, confusion, permanent short-term memory loss, coma, and death in uncontrolled situations (Perl et al. 1990). Unfortunately, 153 human consumers suffered toxicity and 3 died. The toxin responsible for ASP had a neurotoxic effect due to neuro-excitory amino acid domoic acid secreted by pinnate diatom known as *Nitzschia pungens* Grunow (Rao et al. 1988 and Bates et al. 1989). The repeated outbreak of ASP in P.E.I has made the diatom *Nitzschia pungens* in the worldwide distribution of toxic species, and since then, no cases of ASP poisoning have been reported in Canada due to regular monitoring. In 1991, however, there was a toxic bloom outbreak in Monterey Bay California. In this case, although DA was the same, it did not affect humans; it rather was spread from *Engralis mordax* to pelicans and cormorants (Lefebvre et al. 2001). However, this time domoic acid was produced by another diatom species known as *Pseudo-nitzschia australis*, which was not known earlier as toxic species (Garrison et al. 1992). Unlike ASP toxicity by DA, the toxicity by *P. australis* entered the food chain from diatom producers to anchovies to sea birds. The bloom of *Pseudo-nitzschia australis* in the Montegary bay California was coincident with a large number of mortality in brown pelicans and brandt's cormorants. Equally, the shellfish exhibited a large amount of toxins after ingesting marine phytoplanktons. To date, about 49 species of *Pseudo-nitzschia* have been identified and about 26 recorded for producing DA (Fernandes et al. 2014; Dao et al. 2015; Teng et al. 2016; Lundholm et al. 2017). Studies have shown that salinity as the major factor that affects the growth distribution and production of DA in *Pseudo-nitzschia*. The toxicity and tolerance of *Pseudo-nitzschia* is found in coastal waters, estuarine having greater salinity (Brand 1984; Jackson et al. 1992; Villac et al. 2002; Thessen et al. 2005; Markina and Aizdaicher 2016). It is therefore necessary to monitor the estuaries showing constantly saline waters since it directly influences the conductivity. As seen in our studies in Haryana water sites, region HI-08*/HII-18* during years 2008–2010 and 2012–2014 showed high conductivity obviously due to high salinity with dominance and epidemic population of *Cyclotella menghiniana*. This might release amino acid proline from *C. meneghiniana*, which may cause osmotic stress in aquatic life differently (Schobert 1974) and humans as a neurotoxin (Jacquet et al. 2005) just like DA. Nevertheless, a thorough investigation of the water from such sites needs to be done. Among diatoms, *Pseudo-nitzschia pungens* (Grunow ex Cleve) Hasle is one of the most common domoic acid producing diatom found worldwide (Hasle 2002; Casteleyn et al. 2008; Lim et al. 2014; Kim et al. 2015b). Since toxic blooms are not only pathogenic for shellfish resources, which indirectly influence our economy, but if not monitored, even a small DA production can be fatal for both human and wildlife populations. A few strains of *P. pungens* produce low quantities of DA (Trainer et al. 2012; Lim et al. 2014), which are found in abundance in Mandovi and Zuari estuaries on the West coasts of India (Patil and Anil 2008; Pednekar et al. 2012, 2018). In a study of diatoms collected from estuaries in western coasts of India during monsoons, it was found that Mandovi and Zuari estuaries had habitation of *Pseudo-nitzschia pungens*, *P. multistriata*, and *P. seriata* whereas Zuari estuary showed the presence of only *P. australis* and *P. pseudodelicatissima* (Pednekar et al. 2018). The toxicity of *P. pungens*, which was among the most abundant *Pseudonitzchia*, was influenced by salinity. The study showed that Mandovi estuary, which displays more rainfall than Zuari estuary, had more density of *Pseudo-nitzschia* (21.1%) than the latter (8.8%) in the same year 2008. The probable reason is that higher rainfall brings higher number of nutrients and higher salinity in Mandovi estuary. Even though all the *Pseudo-nitzschia* species were toxic, but those found in Zuari estuary had very low DA levels. Furthermore, isolation and culturing of *Pseudo-nitzschia pungens* under laboratory conditions demonstrated that *P. pungens* had high growth density at high salinity of about 35 and lower salinity (5–10) decreased its growth. The maximum growth of 9.6×10^5 cells mL^{-1} was at a salinity of 25 under laboratory conditions, which were coherent with field growth of *P. pungens* at Zuari estuary of 9680 cells mL^{-1} at a salinity of 20–32 and a temperature of 28–32 °C in non-monsoon climate (Pednekar et al. 2018). Besides salinity, many studies have also shown that nutrient limitation of P or Si is induced with the DA production in *Pseudo-nitzschia* (Bates et al. 1998; Bates and Trainer 2006; Trainer et al. 2012), while some have shown that Cu toxicity and Fe deficiency also play a crucial role in enhancing DA in these diatoms (Maldonado et al. 2002). The reason is that when nutrients are limited, energy is available for DA production (Pan et al. 1998).

16.5.2.2 PUA and Oxylipins

Even though domoic acid is a well-known diatom biotoxin, from the standpoint of reproduction effects on aquatic life, oxylipins from diatoms are of much interest. They are however cytotoxic, lysing the cell membranes and targeting cytoskeleton and calcium signaling pathways. Oxylipins along with polyunsaturated aldehydes are released from diatoms only when they are wounded, thus affecting their grazers. Additionally, diatoms also release reactive oxygen species (ROS) and fatty acid peroxidases, which together are highly lethal for invertebrate reproduction in aquatic life. It was seen that benthic diatom *Phaeodactylum tricornutum* is a producer of oxo acids 12 oxo-(5Z,8Z,10E)-dodecatrienoic acid (12-ODTE) (Ianora et al. 2004) and 9-oxo-(5Z,7E)-nonadienoic acid (9-ONDE), which is a barrier to embryonic cleavage (Pohnert et al. 2002). A study by Ban et al. (1997) describes lethal effects of diatoms on copepod reproductive growth with a fall in hatching rate. Caldwell (2009) observed the arrest of oogenesis in starfish oocytes (*Asterias rubens*) exposed to decadienal at the end of the first prophase of meiosis. However, further maturation of oocyets is initiated by follicular-derived hormone. On exposing the oocytes with 1.5 μg mL^{-1}, decadienal during maturation shows that the cytoplasm becomes lighter and less dense, decreasing the overall diameter of the oocyte. Decadienal is thus cytotoxic to oocyets during prophase/metaphase and thus determines the fertility of diatom-fed starfish. However, not all diatoms are able to produce PUA; some like *Skeletonema marinoi* and non-PUA like *Skeletonema pseudocostatum*, *Thalassiosira rotula*, and *Skeletonema marinoi* were able to produce PUA, and others like *Chaetoceros socialis*, *Chaetoceros affinis*, and *Psueudo-nitzschia delicatissima* were unable to produce PUA (D'ippolito et al. 2005, Fontana et al. 2007, Dutz et al. 2008).

16.5.3 Pollution

16.5.3.1 Metals

Metals are well-known hazard of the fluvial ecosystem affecting organisms of various trophic levels due to their bioaccumulative, persistant, and carcinogenic properties (Pandey et al. 2017). Since diatoms are the chief primary producers of the aquatic environment, metal effects on them are of prime concern globally. At a community level, diatoms showed a shift from uniform diversity to the dominant one, while at the individual level, they respond differently, which resulted in morphological and physiological changes inside cells. At the morphological level, diatoms showed deformities and size reduction in their frustules. Morphological deformities under metal stress were reported globally that can be well visualized in live forms as well as through the permanent slide preparation of diatom frustules (Fig. 16.10b, c and f), while physiological changes are mainly manifested as changes in lipid bodies (number and sizes), protoplasmic content, and percentage of motile cells in the community. Normally, deformities are categorized into four types (valve, striations, raphe, and mixed one). Pandey et al. (Pandey and Bergey 2016; Pandey et al. 2014, 2015) comprehensively described deformities in diatoms under metal stress from the different realms such as in situ laboratory and from the metalliferous sites of India. Pandey et al. (2018) also reported deformities in diatom frustules from fresh, brackish, and marine environments of South Korea contaminated with metals. Similarly, Gautam et al. (2017) reported deformities in diatom frustules from the metal-contaminated areas of Haryana, India. Size reduction in diatoms is a well-known phenomenon, but recent reports showed that diminution of frustules size is more pronounced under metal stress (Fig. 16.7a). For example, significant size reduction was examined in *Gomphonema parvulum* and *Nitzschia palea* from metal (Cd and Zn)-polluted streams (Riou Mort and Riou Viou) of South West France. Similarly, significant size reduction was reported in *Brachysira vitrea* (>60%) collected from an abandoned mining area in Portugal (Luís et al. 2011). Barral-Fraga et al. (2016) reported size reduction in different diatom species (*Amphipleura pellucida*, *Nitzschia dissipata*, *Nitzschia fonticola*, and *Nitzschia palea*) treated with arsenic under laboratory conditions. Pandey and Bergey (2016)

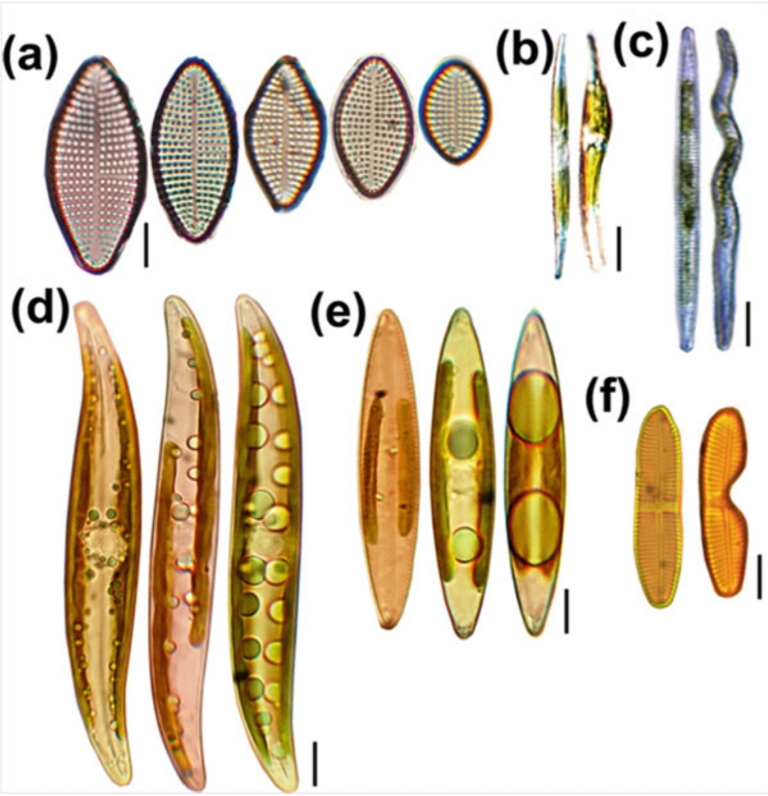

Fig. 16.7 (**a**) Size reduction in marine diatom *Delphineis surirella*; scale bar, 8 μm. (**b**, **c**, **f**) Deformities in diatoms *Nitzschia* sp., *Ulnaria ulna*, and *Achnanthidium breviceps*; scale bar, 10, 20, and 10 μm, respectively. (**d**, **e**) Lipid bodies in *Pleurosigma normanii* and *Navicula directa*; scale bar, 10 μm under metal stress

also reported size reduction in different diatom species (*Achnanthidium minutissimum*, *Brachysira brebissonii*, *B. microcephala*, *Fragilaria capucina*, *Pinnularia conica*, and *Ulnaria ulna*) collected from metalliferous sites of Rajasthan, India (Fig. 16.7b). Despite various reports, size reduction in diatoms is not considered as prominent feature for specifying metal stress.

Metal stress leads to physiological alterations in live diatoms. Lipid bodies are considered to be the reserve food material in diatoms. Under metal stress, their numbers, sizes, and percentage of biovolume contribution in single cells increased (Pandey et al. 2018; Gautam et al. 2017) (Fig. 16.10d, e). Gradual increase in lipid body contribution also leads to progressive decline in their protoplasmic content, which was already reported under nutrient stress conditions (Fig. 16.10b). Altered motility in diatom frustules was also examined under metal stress (Pandey and Bergey 2016). Similarly, the inhibitory effect of metals (Cu, Co, Hg, Ni, Zn, and Fe) on the motility rate of lab-cultured diatoms (*Navicula grimmei* and *Nitzschia palea*) was also reported by Gupta and Agrawal (2007).

Among the various water bodies investigated to prepare a diatom database during 2008–2010 and 2012–2014, in Haryana we found valve deformities in *Cymbella affinis* found in Rani Lake of Jind, as seen in Fig. 16.8.

However, it was rarely found at Sannhit Sarover (Kurukshetra), Damdama Lake, and Yamuna River, and *Gomphonema pseudoaugur* at HII-3 (Saraswati River, Kurukshetra), as seen in Fig. 16.9. One thing that is common in all these water sites is that they were in a holy place like a temple where there is a use of a variety of chemicals like vermillion, plastics, and associated paint along with detergents used by people bathing at these sites before laying their homage inside temples. Vermillion is a source of mercury and lead and is one of the major ingredients offered in temples and later dumped in the water sites near them. The study showed that the water of Saraswati River, Kurukshetra, had a strong affinity for Pb and Se (Gautam et al. 2017). The abundance of *G. pseudoagur* in this water body further demonstrates its tolerance to heavy metal pollution. *G. pseudoagur* was found in all 11 different water bodies investigated during 2012–2014; however, its abundance was highest at site H03(HII-3). Sabater (2000) has reported dominance of *Gomphonema parvulum* at the sites contaminated with mine tailing spills enriched with heavy metals (Pb, Zn, As, Cd, and Cu). Therefore, we presume valve

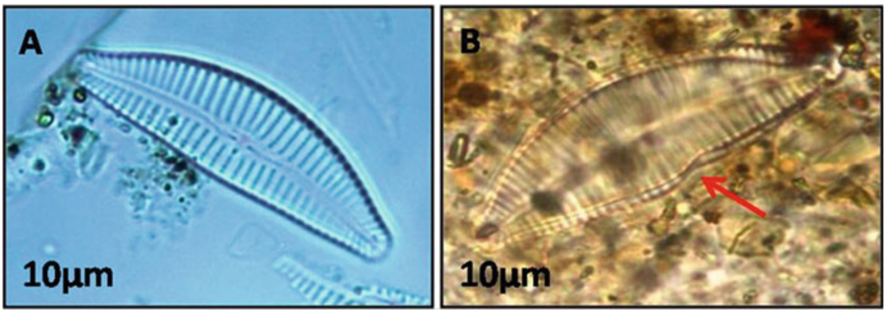

Fig. 16.8 Optical images of deformed *Cymbella affinis* found at Lake Rani Haryana, India, showing deformity at the ventral side, slightly away from the central area

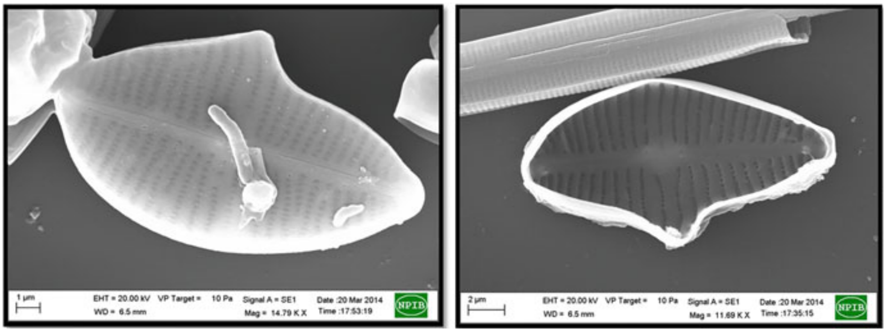

Fig. 16.9 SEM images of deformed *Gomphonema pseudoaugur* collected from Saraswati River, Pehowa, Kurukshetra (HO_3) site of Haryana, India. (Requested with permission from Gautam et al. (2017))

abnormalities to be terratological due to anthropogenic pollutions. These are mainly industrial wastes, agricultural wastes, drought, intensity of sunlight, increased temperature, change in velocity of water, and sedimentation of rocks but majorly affected by heavy metal stress (Pandey et al. 2014, 2015, 2017, 2018; Gautam et al. 2017; Pandey and Bergey 2016; Antoine et al. 1984; Morin et al. 2012). The morphological changes include variation in the valve outline, striae pattern, costae and septae size, modification in raphae, and raphae canal pattern (Fig. 16.9). This was accompanied by *G. pseudoaugur* enriched with lipid bodies in metal stress, which needs a thorough study of the mechanism responsible for it.

16.5.3.2 Drugs

Since the last two decades, researchers have shown increasing interest in the ecological effects of pharmaceuticals and personal care products, tons of which are released into the environment every year (Halling-Sørensen et al. 1998; Hirsch et al. 1999). The vast majority of these studies have ignored to diagnose the effects of these chemicals on diatoms. Similarly, herbicides' effects on diatoms have been rarely reported. Diatoms are the main primary of aquatic ecosystems, and the effects of artificially made chemicals have been a matter of global concern. These chemicals may bioaccumulate, are persistent, and can transfer from one trophic level to other, ultimately affecting humans. Hagenbuch and Pinckney reported reduced and eliminated diatom (*Cylindrotheca closterium* and *Navicula ramosissima*) motility as a toxic effect of antibiotics (ciprofloxain, lincomycin, and tylosin) (Hagenbuch and Pinckney 2012). Similarly, herbicides (maleic hydrazide) are reported to cause induction of nucleus alterations and silica cell wall abnormalities in several diatom genera (*Navicula* and *Nitzschia*) (Debenest et al. 2008, 2010). Debenest et al. reported the toxic effect of pesticides and xenobiotics compounds on the diatom cytology and cell ultrastructure, cell metabolism, and community species composition (Debenest et al. 2008, 2010).

16.5.3.3 Sewage

There is a continuing need for new and improved methods of monitoring the state of the aquatic environment. One such is for monitoring eutrophication in aquatic ecosystems. Sewage discharge in the water bodies leads to a marked community shift, especially of autotrophic organisms. Diatoms are the important constituent of autotrophic microflora, thus effectively helping in understanding the effect of sewage discharge in the aquatic environment. For example, Tornés et al. (2018) reported higher proportions of teratological forms as well as the prevalence of diatom taxa tolerant to sewage pollution. Several researchers also reported using the sewage water for the cultivation of lipid-rich algae (especially diatoms consortia), which can be used for biodiesel production (Marella et al. 2018). Recent reports also advocate using DNA metabarcoding of diatoms for efficient detection of spatial and temporal community response to wastewaters and also in understanding community dynamics when released in the aquatic environment (Chonova et al. 2019). Irregular and unregulated discharge of sewage in the water bodies disturbs its ecological health, which may lead to cascades of events such as algal blooms, deterioration of water quality, foul smell, death of fishes, etc. Thus, proper biomonitoring of sewage discharge in the water bodies is required to protect the natural integrity of the water bodies.

16.5.3.4 Plastics

Plastics and their derivative microplastics are widely distributed in the aquatic environment, causing serious hazards on residing flora (algae) and fauna (zooplankton, fishes, etc.) (Feng et al. 2020). Diatoms were the most abundant, widespread, and diverse group of plastic colonizers, which mainly include genera such as *Mastogloia*, *Haslea*, *Nitzschia*, *Cocconeis*, *Achnanthes*, centric diatoms, *Amphora*, and *Cymbella* (Reisser et al. 2014). It seems that diatoms have a tremendous potential to interact with microplastic in the aquatic environment. As a primary producer, diatoms are an indispensable part of maintaining a balanced aquatic ecosystem (Pandey et al. 2017). Without an ingestion process, diatoms are a better choice for detecting environmental threats caused by microplastic pollution (Zhang et al. 2017). For example, Zhang et al. (2017) reported inhibition of growth and photosynthesis (chlorophyll content and PSII decreased) due to adsorption and aggregation of microplastics on marine diatom *Skeletonema costatum*. Plastic colonizer diatom *Chaetoceros neogracile* showed allelopathic effects as a significant and rapid decrease in red chlorophyll fluorescence, relative cell size, and cell complexity when treated with cells of dinoflagellate *Alexandrium minutum* (Lelong et al. 2011). Recent reports also showed that interactions between plastics and marine algae lead to the formation of macroalgal bloom in the marine environment, which is a matter of great concern and needs immediate attention (Feng et al. 2020). Finally, it seems that plastics can affect diatoms' morphology and physiology, which provides evidence for understanding the risks of plastics.

16.5.3.5 Environmental Effluents

In our earlier work, we reported the simulation of six different types of environmental pollutants (coded as set A1 (control) and a set of seven different effluents were coded as A2-Paint; A3-*Eichhornia crassipes*; A4-Sewage; A5-Detergents; A6-β-Propranolol; A7-Petrol; and A8-Sodium metasilicates) and their effect on diatom *Nitzschia palea* cell density, lipid, and morphology (Ahirwar et al. 2020). It was found that sewage water increases the cell density of diatoms as compared to conditions when there were high silicates, excessive oil spillage, competition with bigger phytoplanktons, and β drugs, to name a few, as seen in Fig. 16.10 (Ahirwar et al. 2020). The sewage plants and industrial effluents also dispose of high nitrates, which are an essential component required for the growth of diatoms.

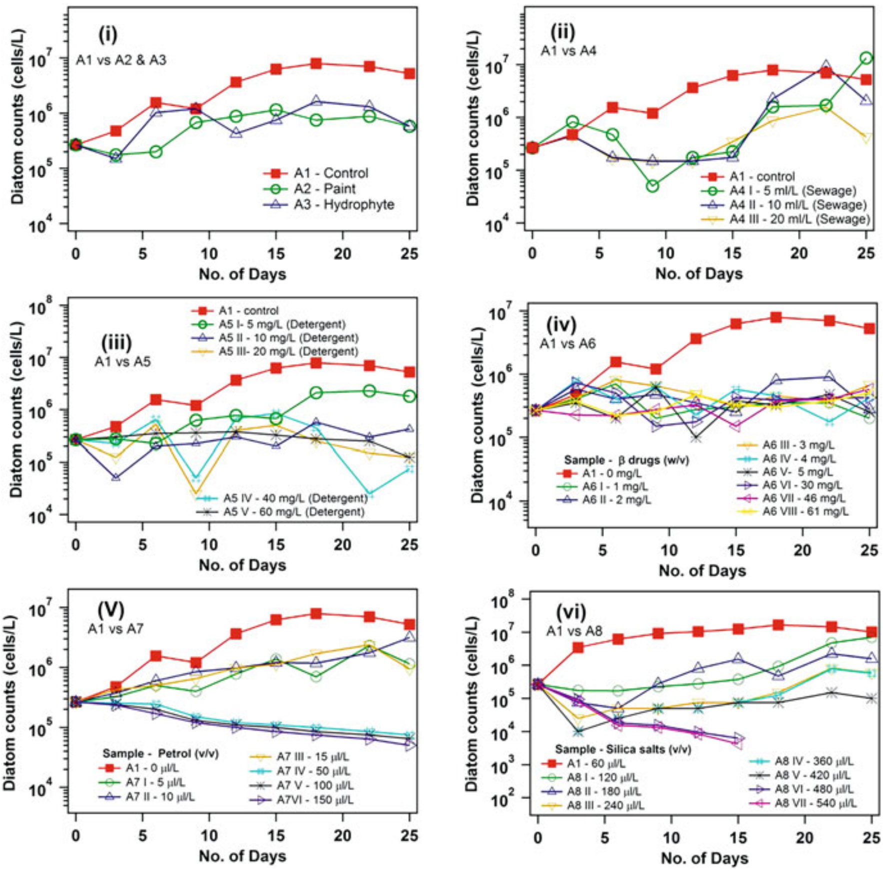

Fig. 16.10 Diatom cell count/L in different sets such as control (A1), paint (A2), hydrophyte (A3) (*Eichhornia crassipes*), sewage water (v/v) (A4), detergents (w/v) (A5), β-propranolol hydrochloride (w/v) (A6), crude petrol (v/v) (A7), and silica salts (w/v) (A8) plotted against daily intervals for 25 days. (Reproduced with permission from Ahirwar et al. (2020))

Pharmaceutical drugs like β propanolol drugs, on the other hand, are quite dangerous as they inhibit Hill's reaction in photosystem II of photosynthesis (Corcoll et al. 2012). Eutrophication is a common phenomenon seen, especially in lakes, rivers, and ponds, which affects the diatom density and community abundance since they being higher plants consume all nutrients and sunlight, letting diatoms die ultimately in this competitive survival. Leached paints in aquatic systems are also harmful to diatom growth since they change the ionic strength and pH of water. Petrol, on the other hand, blocks the gaseous exchange on the surface of the cell, inducing hypoxic conditions, thus leading to death. Excess silicates form precipitates on the cell surface, again resulting in hypoxic conditions fatal for the cell's growth. However, the most toxic effect was seen in set A6 (β propanolol drugs), A7 (high range of petrol), and A8 (high range of metasilicates), whereas moderate amounts of petrol (5–15 μl/L), silica (60–120 μl/L), and sewage (5 mg and 10 mg/L) had no effect on diatom growth as well as lipid production.

16.6 Possible Impacts

The pollutants and toxic and invasive diatom blooms are threat to our aquatic environment. They are responsible for morphological plasticity in diatoms. Environmental and anthropogenic changes in the aquatic environment affect the normal biodiversity of residing diatom community. As the chief primary producers of the aquatic environment, effect on diatoms directly or indirectly affect the organisms of various trophic levels, disturbing the ecological balance of the food chain and food web; these changes include various catastrophic phenomena such as the occurrence of harmful algal blooms, changing population dynamics of the aquatic ecosystem, and population dynamics of the aquatic ecosystem.

16.7 Possible Solutions

The marine microorganisms comprise majorly of diatoms that are reservoirs of polysaccharides (Lancelot and Mathot 1985). Polysaccharides in diatoms play a major role in microenvironment alteration (Gautier et al. 2006; Tesson et al. 2008), adhesion (Faraloni et al. 2003), colony support (Wustman et al. 1998; Mcconville et al. 1999), motility (Gordon and Drum 1970; Kröger and Poulsen 2008), and maybe antiviral activity (Lee et al. 2006).

Naviculan, a sulfated polysaccharide, was isolated from diatom *Navicula directa* (W. Smith) Rales from deep sea water from Toyama Prefecture, Japan, have hyaluronidase inhibitory effects (Kubo et al. 2002). These sulfated polysaccharides have antiviral properties that have a wide range of inhibition against viruses with protein envelopes like herpes simplex virus and human immunodeficiency virus. The molecular weight of naviculan was estimated to be 2.25×10^5 by HPLC with IR spectrum showing sulfate groups at 1252 cm^{-1}, along with SO stretching. The sugar content was mainly fucose 26.6%, xylose 25.0%, galactose 20.7%, mannose 13.1%, and rhamnose 8.7%. The total protein content was about 15.1%. The antiviral properties of naviculan were tested against herpes simplex virus strain 1 (HSV-1) (HF strain), HSV-2 (UW-268 strain), and influenza A virus (NWS strain, H1N1) (IFV) (Lee et al. 2006). The results indicated that naviculan has inhibitory effects against these virions at 10 and 100 mg/mL. Thus, naviculan has shown its inhibitory effects against HSV-1 binding onto host cells and also its penetration into the host cell at an inhibitory concentration of IC_{50}. Much later, *Navicula* diatom was also studied for its antioxidant and drug-like properties cultivated at different wavelengths of light (white, red, and blue) (Fimbres-Olivarria et al. 2018). It was found that the polysaccharide extracts of *Navicula* also contain glucose, rhamnose, galactose, mannose, and xylose grown at each wavelength. The sulfur content was however higher in *Navicula* grown in white light than those grown in red and blue lights. The antioxidant property of extracts from *Navicula* cultured at three wavelengths was tested by doing a scavenging activity assay on stable DPPH (2,2-diphenyl-1-picrylhydrazyl radical). The scavenging rate of DPPH varied from 14.0 to 48.7% when DPPH concentrations were taken from 25 to 200 mg/mL. The sulfated polysaccharide extract from *Navicula* cultivated in white light showed the maximum scavenging activity of 200 mg/mL compared to 48.7 ± 3.1% for blue light and 27.2 ± 2.1% for those from red light. This shows sulfated polysaccharides as a suitable candidate for antiviral drugs against the pathogenic and some robust virions, which may be a potential candidate to explore for drugs against Covid-19 too.

16.8 Conservation Efforts and Recommendations (Central Government, State Government, Local Administration, and Society)

The fundamental role of the algal phycosphere is a key meeting place for shaping phytoplankton–bacteria relationship as partners and antagonists and supports the proposition that the phycosphere's pivotal role is that of the rhizosphere in plant–microorganism relationships (Cole et al. 1988). However, while the concept of the phycosphere has been widely adopted, there is sporadic experimental evidence for its occurrence within diatom–bacteria associations. These interactions face challenges associated with examining exchanges and interactions within the minute volumes occupied by phycospheres. While the coupling of eco-genomics and analytical chemistry has recently provided important new perspectives on the nature of phytoplankton–bacteria interactions (Amin et al. 2015; Fouilland et al. 2014), the next step must be to explore these approaches from the level of bulk, culture-flask analyses to the scale of the phycosphere microenvironment. While achieving this will be far from trivial, new tools and approaches are beginning to provide previously unattainable capacity to explore in the phycosphere. Beyenel et al. (Beyenal et al. 2014) reported microsensors and microelectrodes to measure microscale chemical changes in the rhizosphere (Revsbech et al. 1999), while Zheng et al. (2015) advocated using micromanipulation techniques for examining microbial communities within specific microenvironments, such as the gut of the termite. Approaches of this kind could also be applied to sample the microscale chemical and microbiological features of the phycosphere. New tools to examine the genomic characteristics of microbial assemblages at the microscale, including the development of low-volume metagenomic (Rinke et al. 2016), along with single-cell genomic (Swan et al. 2013) and transcriptomic (Wang et al. 2015) approaches, provide an avenue for characterizing microbial processes at the molecular level inside the phycosphere. Other technologies including microfluidics (Son et al. 2015) and nanoscale secondary ion mass spectrometry (NanoSIMS) (Krupke et al. 2015; Raina et al. 2017) also provide the capacity to interrogate microbial interactions and chemical transfers within a microscale context. A further significant, challenge will then be to take these approaches out of artificial laboratory settings and into the natural aquatic environment. These targeted approaches for zooming in and teasing apart the dynamics of the phycosphere will ultimately provide a clearer perception and a greater recognition of the importance of this specific microenvironment within phytoplankton–bacteria interactions, helping to deliver more robust insights into the basal function of aquatic ecosystems.

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Chapter 17
Plant Diversity at Ecosystem Level in India: Dynamics and Status

S. S. Dash, Sanjay Kumar, and A. A. Mao

17.1 Introduction

India is the land of spirituality, with the ethical principle of "Jivah Rakhshati Rakhshatah" (protect life and be protected), and has conserved all types of creations of mother earth since time immemorial, and it further established the delicate balance between humans and nature. India being the largest democracy in the world and known for its eternal value system, directs its people to protect and conserve nature so as to safeguard the forest and wildlife for posterity. India's rich and unique biodiversity represents 11.4% of all species on Earth. The range of ecological habitats and environmental conditions in India have produced all possible types and extremities of climatic conditions suitable for supporting wide varied types of ecosystems with a high level of endemism, making it one of the world's megadiverse countries. It is estimated that India's native vegetation is composed of about 50,012 species of plants, which form the conspicuous vegetal cover and various complexes of about 21846 taxa of angiosperms, of which 28% of the Indian plants are endemic to the country (Mao et al. 2021).

Some of the significant features of the Indian flora are a high degree of endemism and higher incidence of rare and threatened plant species, the confluence of species from different floral elements from three major bio-geographic realms, namely the Indo-Malayan (the richest in the world), the Indo-Arctic (Eurasia), and the Afrotropical. The occurrence of many endemics and high affinities of plants is suggestive of Indian flora having been a center of isolation, speciation, and adaptive evolution of many biotas.

The interaction of the high degree of species diversity and physical characteristics of the various habitats has evolved a number of unique ecosystems in India. These ecosystems exist at any scale, for example, from a small alpine pool up to the size of

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the entire biosphere reserve. However, lakes, marshes, and forest stands represent more typical examples of the areas that are compared to the ecosystem diversity. These are the largest scale of biodiversity, and within each ecosystem, there is a great deal of both species and genetic diversity. However, in the post-CBD era, the perception of an ecosystem has changed from a diversity of species to recognizing and acknowledging the diverse ecological services and functions they offer. Today, it is understood that different ecosystems reinforce a wide range of goods and services for overall human well-being, including food security and the survival of the inhabitants.

However, in the recent past, many of these natural ecosystems have been suffering from heavy pressures due to rapidly expanding economic growth and strong livelihood demands owing to a shortage of natural resources. In addition to this, continuing anthropogenic disturbances such as agricultural expansion, overgrazing, habitat degradation, deforestation, and forest fires have also been adversely affecting the biodiversity of the ecosystems. It has also been predicted that such disturbances may give way to invasive alien species, loss of pollinators, disease, and pest outbreaks. These dramatic declines in local biodiversity will have a negative impact on the livelihood and survival of millions of people all along the country. Hence, greater efforts are needed to build the current level of scientific understanding of ecosystem dynamics, functioning in the changing trend, and to create awareness of the significance of such functioning.

The maintenance of these ecosystems, which can be termed as "Life Support Systems of Earth," is considered vital for the preservation of genetic diversity. The sustainable utilization of species and ecosystems supports millions of rural communities both directly and indirectly. India's plan adopts conservation of all wildlife, i.e., wild flora and wild fauna; these have an ecological value to the ecosystem. Therefore, it is the need of the hour that ecosystem management is to be prioritized to enhance the carrying capacity of major ecosystems to provide important services. We have explored here various recognized ecosystems of India and their status, thereby maintaining the ecological integrity and sustainability of various ecosystem services. The major ecosystems discussed here included two broad categories of terrestrial (forest ecosystem, desert ecosystem, grassland ecosystem) and aquatic ecosystems (mangroves and wetlands).

17.2 Terrestrial Ecosystems

17.2.1 Forest Ecosystems

Since 1980, the forested areas in India have been steadily increasing, mainly due to the regeneration of woodland, shrubland, and plantation forests. As per the latest estimation, out of the total forest cover of 702,979 km^2 or 24.16% of the geographical area in India, moderately dense forest (canopy cover 40–70%) occupy the maximum area, i.e., 9.39% of the total geographic area, followed by open forest

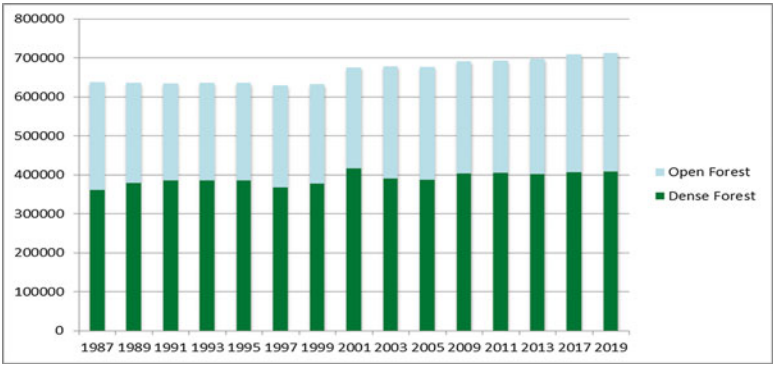


Fig. 17.1 Trend of open and dense forest area in the past two decades (Source: FSI reports)

(canopy cover 10–40%) with 9.27% and very dense forest (canopy cover >70%) with only 3.02% of the geographical area (Forest Survey of India 2019). There is an additional 1.41% of scrub vegetation. India's forest cover grew by 0.20% annually during 1990–2000 and has grown at the rate of 0.7% per year from 2000 to 2010 and 0.90% during 2010–2019 (Fig. 17.1). India is one of the ten most forest-rich countries in the world. In 2018, the total forest and tree cover in India increased to 24.39% or 802,088 km^2. It increased further to 24.56% or 807,276 km^2 in 2019. The per capita availability of forest land in India is one of the lowest in the world, 0.08 ha, against an average of 0.5 ha for developing countries and 0.64 ha for the world (FAO 2018). The per unit area forest stock volume is 5167 (m. cub), while India gained the forest cover by 0.3% of the total forest cover of 2010 (Forest Survey of India 2019).

The forest ecosystems of India are highly diverse, dominated by a wide range of floral elements depending upon the physiography, climatic environment, and elevations. For example, the tropical forest composition of Terai Himalaya and northeast India or Southern Western Ghats are different. Similarly, the swamp forests of Indo-Gangetic plains to that of Gujarat coast are different. The most recognized and acceptable forest classification of India was proposed by Champion and Seth (1968), where India's forests were classified into 6 "major groups," 16 "subgroups," and more than 200 "subgroup categories." Each of the major forest groups or the unit of vegetation is distinct from each other by its physiognomic, structure, and floristic composition (Chaturvedi et al. 2017).

The tropical forest ecosystems are divided into six major groups depending on the floral composition and rainfall: wet evergreen forests, characterized by a dense growth of tall trees, rich in climbers, lianas, epiphytes, and shrubs but poor in herbs or grasses. These types of forest ecosystems are found mainly in the Andaman Islands, southern Western Ghats, Eastern Ghats, and Northeast India. Giant trees with buttressed bases and trunks that are unbranched over 30 m with a close canopy and several strata are characteristic of these forests. There is variation in the composition of the canopy trees not only from north to south but also depending upon the soil, slope, and altitude. *Dipterocarpus–Kingiodendron–Vateria* and

Dipterocarpus–Mesua–Palaquium associations in the south, *Dipterocarpus–Planchonia–Hopea* series in Andaman, and *Dipterocarpus–Terminalia–Cinnamomum* in northeast are common tree compositions in these forests. Tropical semi-evergreen ecosystems occur in areas where annual average rainfall varies between 200 and 250 cm. The deciduous tree species dominate these forests in association with evergreen species. These forests are also well stratified (3–4 stratum) with giant trees at upper canopy layers and a rich carpet layer of herbs, grasses, and ferns in the undergrowth. *Dipterocarpus alatus–Petrocymbium tintorium–Sterculia campanulta* in islands, *Acrocarpus fraxinifolia–Aglaia hiernii–Castonoipis tribuloides* in Northeast India and Arunachal Pradesh, and *Shorea robusta–Terminalia alata–Pterocarpus marsupium–Dalbergia panicualata* in Central India and Eastern Ghats are common. In Eastern Himalaya, different species of bamboos dominated the middle stratum (Dash and Singh 2017; Chauhan 1996). Moist deciduous forests are characterized by an open canopy of scattered mixed deciduous species reaching a height of 25 m or more. There is a combination of deciduous and evergreen smaller trees and dense growth of shrubs and perennial herbs in the second and lower story. *Shorea robusta–Bridelia squamosa–Hardwickia binata–Stereospermum chelonoides* are common in this forest. Littoral and swamp forests are characterized by the dominance of halophytic evergreen plants. The species composition depends on the degree of waterlogging. *Sygygium cumini*, *Mimusops littoralis*, *Trewia nudiflora*, *Drypteris roxburghii*, and *Sophora tomentosa* are common in this forest. *Cycas rumphii* and *Pandanus* are common in islands.

The tropical dry and moist deciduous forest ecosystems of India accounted for 58%of the total forest area. The proportion and dominance of evergreen and deciduous elements usually determine the kind of forest. In the former, evergreen species in the lower story, frequently accompanied by a rich growth of undershrub and perennial herbs, gives the forest a more or less luxuriant green outlook, while in the latter, the deciduous elements are more dominant so that the entire forest looks dry in almost all the time of year. The distribution of floral elements is very much specific depending upon the physiography, phytogeographical region, and soil texture. The greater part of this kind of forests occurs on the lower hillslopes and ravines, receiving an average annual rainfall of about 150 cm or more in the Eastern Ghats (Western regions of Orissa), Central India (Southern Madhya Pradesh), foothills of Himalaya, and parts of northeastern states. The dominant trees of the top story are *Shorea robusta*, *Pterocarpus marsupium*, and *Terminalia alata*, while *Bridelia squamosa*, *Cleilstanthus collinus*, *Mallotus philippinensis*, and *Kydia calycina* are dominant in the middle story. Based on the tree assemblage, different communities of forest ecosystems are recognized with different tree biomass, carbon density, and carbon accumulation (Chaturvedi et al. 2011a, b, 2012, 2017).

Tropical thorn forest ecosystems are dominated by low thorny hard-leaved evergreen trees, and xerophytes generally grow on very shallow and poor soil, mainly found in the arid region of Gujarat and Rajasthan. The trees are bushy, mostly widely scattered, forming a low branching crown under 10 m. The common associates include *Acacia chundra*, *Anogeissus latifolia*, *Butea monosperma*,

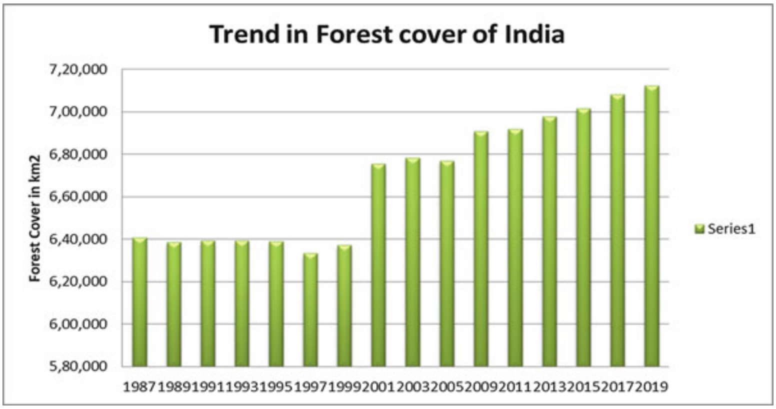


Fig. 17.2 Trends of forest cover during last three decades (1987–2019)

Diospyros melanoxylon, *Mitragyna parvifolia*, and *Diospyros* spp. Climbers are scarce and those found are mostly slender and annual. Epiphytes are represented by only a few species of the partly parasitic members of the family Loranthaceae. In the Shivalik region, prolonged dry season evolved growth of thorny stunted trees and shrub species. Such an ecosystem is dominant with *Acacia catechu*, *A. nilotica*, *Phoenix sylvestris*, *Euphorbia royleana*, *Randia* spp., *Rhus* spp., *Ziziphus* spp., etc.

The dry evergreen forest ecosystem is found in the east coast from Nellore down to Tirunelveli, Mamandoor valley in Chittoor division, Nagavera in the South Cuddapah division of Andhra Pradesh. These forests are characterized by small coriaceous leaved evergreen trees, reaching up to 12 m in height, forming a complete canopy with short boles and spreading crowns. The top layer of trees is composed of *Albizia amara*, *A. lebbeck*, *Acacia leucophloea*, *Azadirachta indica*, *Buchanania angustifolia*, *Diospyros chloroxylon*, *Manilkara hexandra*, etc. (Fig. 17.2).

The broadleaved subtropical forest ecosystems occur predominantly in Himalaya, Central India Eastern Ghats, and Western Ghats where the elevation ranges from 1000 to 1800 m. These forests are characterized by an abundance of climbers and epiphytic ferns and orchids and dense growth of evergreen broadleaved trees. Many species of genus *Quercus*, *Rhododendron*, *Syzygium*, *Anogeissus*, *Alnus*, *Toona*, *Mallotus*, *Castanopsis*, *Ficus*, *Sapium insigne*, *Bishofia javanica*, *Cassia fistula*, and *Terminalia bellirica* are found in Himalaya, while in Central India and Odisha *Michelia champaca*, *Mangifera indica*, *Syzygium cumini*, *Manilkara hexandra*, *Symplocos laurina*, *Salix tetrasperma*, etc. are common. In the Northwestern Ghats of Maharashtra, these forests are dominated by *Actinodaphne angustifolia*, *Alseodaphne semecarpifolia*, *Beilschmiedia dalzellii*, *Cinnamomum verum*, *Cryptocarya bourdillonii*, *Elaeocarpus serratus*, etc. Subtropical coniferous forests of Western Himalaya are dominated by *Pinus roxburghii* while in Eastern Himalaya by *Tsuga dumosa* and *Pinus kesiya*. *P. roxburghii* often forms pure patches on the hill slopes and sometimes with association with *Albizia procera*, *Lyonia ovalifolia*, *Myrica esculenta*, *Quercus oblongata*, *Mallotus philippensis*, *Alnus nepalensis*, etc.

The temperate forest ecosystems occur between 1800 and 3500 m in the Himalayas. On the basis of species composition and altitudes, temperate forest ecosystems are categorized into the broadleaved temperate forest, mixed temperate coniferous forest, West Himalayan deodar forest, dry Himalayan temperate scrubs, and coniferous forests (Singh et al. 2019). East Himalayan broadleaved temperate forests are (between altitude 1800 and 2800 m asl) characterized by mostly *Laurels*, *Quercus*, *Acer*, *Castanopsis*, and *Magnolia*, mixed with different species of *Rhododendrons* in different proportion, while in Western Himalaya, these are represented by the common tree species like *Quercus floribunda*, *Rhododendron arboreum*, *Aesculus indica*, *Daphniphyllum himalayense*, *Lyonia ovalifolia*, *Betula alnoides*, etc. (Singh et al. 2019).

The east Himalayan mixed temperate coniferous forests are the unique ecosystems of the world and are mainly found in Arunachal Pradesh and Sikkim. The typically mixed population of *Tsuga–Pinus–Taxus* series of conifers with *Rhododendron* species determines the type of vegetation. *Tsuga–Abies–Rhododendron* series is common in West Kameng district of Arunachal Pradesh, pure stands of *Cupressus* in Upper Siang of Arunachal Pradesh, *Abies–Taxus* in West Siang or *Picea–Larix–Abies* in West Kameng, Tawang districts of Arunachal Pradesh, and Dombyeng valley of North Sikkim. The important *Rhododendron* species that are found mixed are *Rhododendron arboreum* subsp. *cinnamomeum*, *R. arizelum*, *R. campylogynum*, *R. cerasinum*, *R. dalhousiae*, *R. falconeri*, *R. faucium*, etc. In contrast, the West Himalayan coniferous (deodar) forests are distributed between 2200 and 3200 m. Pure stands of *Cupressus torulosa* and *Quercus–Abies pindrow*, *A. spectabilis*, *Cedrus deodara*, *Picea smithiana*, *Pinus wallichiana*, and *Taxus wallichiana* are common in forests of Uttarakhand and Himachal Pradesh between elevations of 2500–3500 m.

Subalpine forest ecosystems occur between 3500 and 4200 m and experience extremely low temperature and humidity. These are climax types of vegetation characterized by stunted deciduous or evergreen floral elements with conifers. *Betula utilis* sometimes forms pure stands in places like on the way to Valley of Flowers, near Dhanasi pass in Nanda Devi National Park. In Eastern Himalaya, in higher altitudes above 4000 m, the vegetation comprises stunted bushy growth of *Juniperus* sp., *Rhododendron lepidotum*, *R. anthopogon*, *Sorbus microphylla*, *Berberis angulosa*, *B. macrosepala*, *Rosa sericea*, etc., while in Western Himalaya, subalpine scrub vegetation comprises *Astragalus*, *Caragana*, *Cotoneaster*, *Lonicera*, *Rosa*, *Salix*, *Spiraea*, *Viburnum*, etc. (Shukla and Srivastava 2015). The alpine forest maintains plants of great medicinal value, viz. *Aconitum ferox*, *Coptis teeta*, *Gentiana kurroo*, *Neopicrorhiza scrophulariiflora*, *Saussurea* spp., *Rheum nobile*, etc. (Singh et al. 2019). The lower elevations of this zone support shrubby species of *Rhododendron*, *Berberis*, *Cotoneaster*, *Euonymus*, *Gaultheria*, *Salix*, and *Vaccinium*, while xerophytic scrubs with many herbs and grasses form dense tussocks in the upper elevation. The alpine zone provided habits for several orchids,

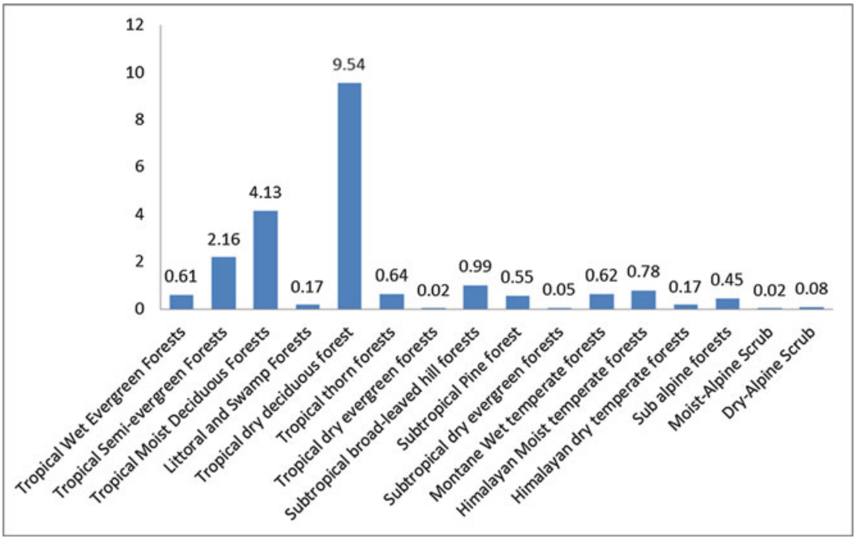


Fig. 17.3 Percentage of various types of forest in the total geographical area of India

especially terrestrial orchids where they grow in association with other herbaceous elements.

The geographical position, physiography, and varied climatic conditions of the Himalayas have altogether contributed to the high endemism of plant species. The altitudinal gradient of the mountain ranges is one of the decisive factors in shaping the spatial distribution of species. Western Himalaya contributes 7% of endemic taxa, while Eastern Himalaya contributes 11% of total endemic taxa reported from India (Singh et al. 2015). The distribution of endemic species, their concentration, and the level in the biological hierarchy are particularly important aspects in determining the affinities of plant species. Based on leaf characters, the Himalayan vegetation has been divided into 11 forest formations (Singh and Singh 1987). A comparative account of species similarity index, distribution patterns of growth forms, and life forms for various altitudinal zones (with different plant communities) in Western Himalaya shows that highest concentration of species diversity is found in middle altitudinal zones (1500–3000 m) and the percentages of tree, shrub, and climber species in total growth forms decreases with an increase in the altitude while the percentage of herb species increases towards high altitudes (Mao et al. 2021).

The entire Indian Himalayan region is represented by 11,157 taxa of flowering plants belonging to 2359 genera under 241 families (Singh et al. 2019). The first 20 dominating families contribute almost 60% of the total flowering plants found in the Himalayas. *Carex* L. with 183 species is the most dominant genus in Himalaya, followed by *Impatiens* L. (122 species), *Rhododendron* L. (112 species), *Primula* L. (99 species), *Pedicularis* L. (92 species), and *Saxifraga* L. (86 spp.). The first 10 dominating genera contribute 9.06% of the total species in the Himalayas (Singh et al. 2019). The different parentage of major forest types in India is given in

Fig. 17.3, and the type of forest ecosystems as recognized by Champion and Seth with modification by authors is given in Table 17.1.

17.2.2 Desert Ecosystems

Desserts are unique terrestrial ecosystems with barren landscapes and scanty precipitation; consequently, living conditions are hostile both to plant and animal life. The lack of vegetation often exposes the land cover of the ground resulting in high denudation. Desertification is a process of land degradation in arid, semiarid, and dry subhumid areas resulting from various factors, including climatic variations and human activities leading to the loss of productive ecosystem and biodiversity. The process of desertification involves land degradation, loss of vegetation cover, soil erosion, waterlogging, and increase of salinity.

Desertification has long been recognized as a major environmental problem affecting the livelihood of the people and the result of complex interactions among physical, biological, social, cultural, and economic factors. It not only impacts economic growth but also affects social and economic development. The causes of desertification such as overgrazing, land degradation, deforestation, farming practices, urbanization, and land development are continuous processes but can be subjected to control by improved management practices. To reclaim the deserted lands, there is an urgent need to stop and reverse the process of land degradation by sustainable land management practices, groundwater recharge, restoring soil organic matter, conservation of biodiversity, and natural vegetation. According to UNESCO, one-third of the world's land surface is threatened due to the desertification across the world, which affects the livelihood of millions of people who depends on various ecosystem services of this region. Indian deserts can be categorized into the following.

17.2.2.1 Cold Desert

Cold deserts are fragile ecosystems in the rain shadow regions of the Trans-Himalayan zone characterized by extremely low temperatures, great diurnal fluctuations, scanty and erratic rainfall, and heavy snowfall. The total area of cold desert in India is approximately 98,660 km^2 of this about 82,665 km^2 in Jammu and Kashmir, about 15,000 km^2 in Himachal Pradesh, and about 1000 km^2 in Uttarakhand. The vegetation of cold deserts can be categorized into three groups, viz., alpine, typical cold desert elements, and Ossetic vegetation. On closer look, it unfolds astonishing ecological, morphological, and physiological adaptations that help them to thrive in harsh climatic conditions. Specialized habits like cushion or mat-forming, diminutive and bushy habits, plants with deep penetrating taproot systems, and the presence of thick and silvery hairy indumentum are some of the key adaptations in the cold desert. The plants of the cold desert have medicinal and economic potential as they

Table 17.1 Various major forest ecosystems and their subgroups (adopted from Champion and Seth 1968 with modifications)

Forest ecosystem type I: moist tropical forests
1. Tropical wet evergreen forests: (20,054) (AR, AS, GA, KA, KR, MH, ML, TN, NL, AN)
1A. Southern tropical wet evergreen forest
C1 Giant evergreen forest (*Dipterocarpus alatus*, *Hopea odorata*) C2 Andamans tropical evergreen forest (*Dipterocarpus grandiflorus*, *D. pilotus*, *D. kerrii*, *Artocarpus* sp., *Artocarpus gomezianus*, *Calophyllum soulattri*) C3 Southern hilltop tropical evergreen forest (*Dipterocarpus costatus*, *Mesua ferrea*, *Canarium denticulatum*) C4 West coast tropical evergreen forest (*Dipterocarpus indicus*, *Calophyllum apetalum*, *Hopea odorata*, *Palaquium ellipticum*)
1B. Northern tropical wet evergreen forest
C1. Assam Valley tropical wet evergreen forest (*Dipterocarpus retusus*, *Shorea assamica*, *Mesua ferrea*, *Altingia excelsa*) C2. Upper Assam valley tropical evergreen forest (*Dipterocarpus–Mesua* type dominance, *Mesua assamica*, *Ailanthus integrifolia*, *Magnolia doltsopa*, *Quercus lamellosa*, *Dysoxylummollissimum*) C3. Cachar tropical evergreen forest (*Dipterocarpus turnbinatus*, *Palaquium polyanthum*, *Diospyros racemosa*, *Maniltoa polyandra*)
2. Tropical semi-evergreen forests: (71,171) (AR, AS, BR, GA, KR, KR, MH, MN, ML, MZ, NL, OD, TN, TR, UP, WB, AN)
2A. Southern tropical semi-evergreen forest
C1. Andamans semi-evergreen forest (*Dipterocarpus alatus*, *D. gracilis*, *Pterocymbium tinctorium*, *Terminalia bialata*) C2. West coast semi-evergreen forest (*Terminalia paniculata*, *Lagerstroemia lanceolata*) C3. Tirunelveli semi-evergreen forest (*Hopea utilis*, *Hopea parviflora*, *Kingiodendron pinnatum*, *Stereospermum tetragonum*, *Dalbergia latifolia*)
2B. Northern tropical semi-evergreen forest
C1. Assam Valley tropical semi-evergreen forest (*Syzygium formosum*, *Phoebe hainesiana*, *Magnolia champaca*, *Castanopsis indica*, *Terminalia myriocarpa*)
C2. Cachar tropical semi-evergreen forest (*Artocarpus chama*, *Dipterocarpus turbinatus*, *Pterospermum acerifolium*)
C3. Orissa tropical semi-evergreen forest (*Firmiana colorata*, *Artocarpus lacucha*, *Magnolia champaca*, *Mesua ferrea*)
3. Tropical moist deciduous forests (1,35,492) (AP, AR, AS, BR, CG, GA, GJ, HP, JH, KR, MP, MH, MN, ML, MZ, NL, OD, SK, TN, TS, TR, UP, UK, WB, AN, DD)
3A. Andamans moist deciduous forest
C1. Andamans moist deciduous forest (*Pterocarpus dalbergioides*, *Terminalia bialata*, *Bombax insigne*, *Chukrasia tabularis*, *Lannea coromandelica*)
3B. South Indian moist deciduous forest
C1. Moist teak-bearing forest (*Grewia amicorum*, *Lagerstroemia lanceolata*, *Terminalia crenulata*) C2. Southern moist mixed deciduous forest (*Tetrameles nudiflora*, *Stereospermum tetragonum*, *Dysoxylum gotadhora*, *Ficus nervosa*)
3C. North Indian tropical moist deciduous forest
C1. Very moist Sal bearing forest (*Schima wallichii*, *Dendrocalamus hamiltonii*, *Stereospermum tetragonum*, *Shorea robusta*, *Garuga pinnata*, *Terminalia bellirica*)

(continued)

Table 17.1 (continued)

C2. Moist Sal bearing forest (*Shorea robusta*, *Anogeissus latifolia*, *Terminalia tomentosa*, *Pinus roxburghii*) C3. Moist mixed deciduous forest (*Albizia procera*, *Adina cordiflora*, *Terminalia tomentosa*, *Garuga pinnta*, *Mallotus philippensis*, *Duabanga grandiflora*)
4. Littoral and swamp forests (5,596) (AP, AS, BR, GA, GJ, KR, MP, MH, NL, TN, UP, WB, AN)
4A. Littoral forest
L1. Littoral forest (*Casuarina equsetifolia*, *Calophyllum inophyllum*, *Manilkara littoralis*, *Calophyllum inophyllum*)
4B. Tidal swamp forest (*Phenix paludosa*, *Pandanus* sp., *Casurina* sp.) Mangrove forest (*Bruguiera gymnorrhiza*, *Rhizophora mucronata*, *Kandelia candel*, *Avicennia alba*)
4C. Tropical freshwater swamp forest (*Albizia amara*, *Sapindus emarginatus*, *Tamarindus indica*, *Thespesia populnea*)
4D. Tropical seasonal swamp forest (*Strychnos nux-vomica*, *Phoenix paludosa*, *Porteresia coarctata*)
4E. Tropical riparian fringe forest (*Pterocarpus marsupium*, *Terminalia alata*, T. *bellirica*, T. *chebula*, *Lannea coromandelica*)
Forest ecosystem type II: Dry tropical forests (3,13,617)
5. Tropical dry deciduous forest (AP, AS, BR, CG, DL, GA, GJ, HP, JK, JH, KA, KR, MP, MH, OD, PB, RJ, TN, TS, UP, UK, WB, CH, DD)
5. Tropical dry deciduous forest 5A. Southern tropical dry deciduous forest
C1. Dry teak bearing forest (*Anogeissus pendula*, *Tectona grandis*, *Cochlospermum religiosum*, *Acacia catechu*, *Cassia tora*) C2. Dry red sanders bearing forest (*Pterocarpus santalinus*, *Anogeissus latifolia*) C3. Southern dry mixed deciduous forest (*Terminalia tomentosa*, *Mitragyna parviflora*, *Madhuca indica*, *Butea monosperma*, *Prosopis juliflora*)
5B. Northern tropical dry deciduous forest
C1. Dry Sal bearing forest (*Shorea robusta*, *Anogeissus latifolia*, *Woodfordia fruticosa*) C2. Northern dry mixed deciduous forest (*Acacia catechu*, *Anogeissus latifolia*, *Lannea coromandalica*, *Aegle marmelos*, *Feronia limonia*, *Dalbergia sissoo*)
6. Tropical thorn forests (20,877) (AP, DL, GJ, HR, KA, KR, MP, MH, PB, RJ, TN, TS, UP)
6A. Southern tropical thorn forest
C1. Southern thorn forest (*Acacia catechu*, *Cordia dichotoma*, *Zizyphus mauratiana*) C2. Carnatic umbrella thorn forest (*Albizzia amara*, *Chloroxylon swietenia*, *Azardirachta indica*)
6B. Northern tropical thorn forest
C1. Desert thorn forest (*Acacia jacquemontii*, *Prosopis spicigera*, *Salvadora oleoides*, *Calotropis gigantea*, *Zizyphus nummularia*, *Butea monosperma*) C2. Ravine thorn forest (*Acacia lecophloea*, *Prosopuis spicigera*, *Azadirachta indica*, *Holoptelea intregrifolia*)
7. Tropical dry evergreen forests (937) (AP, TN)
C1 Tropical dry evergreen forest (*Manilkara hexandra*, *Mimusops elegi*, *Diospyrous ebenum*)
Forest ecosystem type III: montane subtropical forests

(continued)

Table 17.1 (continued)

8. Subtropical broadleaved hill forests (32,706) (AR, AS, KA, MP, MH, MN, ML, NL, SK, TN, WB)
C1. Southern subtropical hill forest (*Eugenia wightiana*, *Calaphyllum elatum*, *Cinnamomum sulphuratum*, *Rhododendron nilagaricum*) C2. Western subtropical hill forest (*Cinnamomum* spp., *Cullenia exarillata*, *Elaeocarpus* spp., and *Mesua ferrea*) C3. Central Indian subtropical hill forest (*Machilus macrantha*, *Neolitsea zeylanica*, *Symplocus lauriana*, *Toona*, *Salix tetrasperma*, *Berberis aristata*)
8B. Northern subtropical broadleaved hill forest
C1. East Himalayan subtropical wet hill forest (*Acer oblongum*, *Actinodaphne obovata*, *Alnus nepalensis*, *Beilshmiedia roxburghiana*, *Callicarpa arborea*, *Castanopsis hystrix*, *Dichroa febrifuga*, *Engelhardia spicata*, *Garcinia acuminata*, *Gynocardia odorata*, etc.) C2. Khasi subtropical wet hill forest (*Alnus nepalensis*, *Alcimandra cathcartli*, *Betula alnoides*, *Castanopsis indica*, *Cinnamomum glanduliferum*, *Cryptocarya amygdalina*, *Evodia trichotoma*, *Dysoxylum binectariferum*, *Exbucklandia populnea*, *Terminalia myriocarpa*)
9. Subtropical pine forest (18,102) (AR, AS, HR, HP, JK, MN, ML, NL, PB, SK, UK, WB)
C1. Himalayan subtropical pine forest (*Pinus roxburghii*, *Pyrus pashia*, *Acacia catechu*, *Shorea robusta*, *Terminalia tomentosa*) C2. Assam subtropical pine forest (*Pinus kesiya*, *Pinus roxburghii*, mixed with *Acer oblongum*, *Lithocarpus dealbata*, *Myria esculanta*, *Quercus grifithii*, *Magnolia campbelli*)
10. Subtropical dry evergreen forests (180) (JK)
C1. Subtropical dry evergreen forest (*Olea cuspidata*, *Olea ferruginea*, *Dodonaea viscosa*, *Lindera pulcherrima*, *Morus serrata*, mixed with *Arundinella nepalensis*, *Imperata cylindrica*, *Themeda anathera*, *Saccharum* spp.)
Forest ecosystem type IV: Montane temperate forests
11. Montane wet temperate forests (20,435) (AR, KA, KR, MN, NL, SK, TN, WB)
11A. Southern Montane wet temperate forest (*Ternstroemia gymnanthera*, *Syzygium calophyllifolium*, *Magnolia nilagirica*, *Rhododendron nilagaricum*)
11B. Northern Montane wet temperate forest
C1. East Himalayan wet temperate forest (*Acer hookeri*, *Magnolia campbellii*, *Photinia integrifolia*, *Castonopsis tribuloides*, *Prunus nepalensis*, *Rhododendron* spp.) C2. Naga Hills wet temperate forest (*Exbucklandia populnea*, *Magnolia ovata*, *Prunus*, *Magnolia* spp., *Myrsine semiserrata*)
12. Himalayan moist temperate (25,743) (AR, HP, JK, NL, SK, UK, WB)
C1. Lower Western Himalayan temperate forest (*Quercus incana*, *Q. dilatata*, *Cedrus deodara*, *Pinus wallichiana*) C2. Upper West Himalayan temperate forest (*Quercus semicarpifolia*, *Abies delavayi*, *Abies pindrow*, *Picea smithiana*, *Pinus roxburghii*) C3. East Himalayan moist temperate forest (*Abies desa*, *Tsuga dumosa*, *Picea spinulosa*)
13. Himalayan dry temperate forests (5,627) (AR, HP, JK, UK)
C1. Dry broadleaved and coniferous forest (*Alnus*, *Quercus*, *Ilex*, *Pinus*) C2. Dry temperate coniferous forest (*Pinus girardinana*, *Cedurs deodara*) C3. West Himalayan dry temperate deciduous forest (*Daphne papyracea*, *Coriaria nepalensis*, *Hoppophae rhamnoides*) C4. West Himalayan high-level blue pine forest (*Pinus wallichiana*, *Abies spectablis*, *Betula utilis*, *Sorbus foliolosa*, *Rhododendron campanulatum*) C5. West Himalayan dry juniper forest (*Juniperus macropoda*) C6. East Himalayan dry temperate coniferous forest (*Larix griffithii*, *Picea spinulosa*,

(continued)

Table 17.1 (continued)

Cupressus torulosa, *Tsuga dumosa*, *Taxus wallichiana*) C7. East Himalayan dry juniper/birch forest (*Juniperus recurva*, *Salix elegans*, *Myricaria elegans*)
Forest ecosystem type V: subalpine forests
14. Subalpine forests (14,995) (AR, HP, JK, SK, UK, WB)
C1. West Himalayan subalpine birch/fir forest (*Betula utilis*, *Abies spectabilis*, *Rhododendron campanulatum*, *Pinus wallichiana*) C2. East Himalayan subalpine birch/fir forest (*Larix griffithii*, *Picea spinulosa*, *Cupressus torulosa*, *Tsuga Dumosa*, *Taxus wallichiana*)
Forest ecosystem type VI: alpine forests
15. Moist alpine scrub (959) (AR, HP, JK, SK, UK)
C1. Birch-Rhododendron scrub forest (*Betula utilis*, *Rhododendron pumilum*, *Sorbus wallichii*) C2. Deciduous alpine scrub (*Betula utilis*, *Salix* spp., *Rhododendron anthopogon*, *R. lepidotum*)
16. Dry alpine scrub (2,922) (HP, JK, UK)
C1. Dry alpine scrub (*Juniperus wallichiana*, *Artemisia maritima*, *Berberis asiatica*, *Eurya acuminata*, *Gaultherial* spp., *Potentila* spp.)

Note: The occurrence of different forest ecosystems is based on the State of Forest Report 2019 (ICFRE). The parathesis number denotes area in sq.km covered by each forest ecosystem. Abbreviation for the state names: AN—Andaman and Nicobar, AP—Andhra Pradesh, AR—Arunachal Pradesh, AS—Assam, BR—Bihar, CG—Chhattisgarh, CH—Chandigarh, DD—Dadra and Nagar Haveli and Daman and Diu, DL—Delhi, GA—Goa, GJ—Gujarat, HP—Himachal Pradesh, HR—Haryana, JH—Jharkhand, JK—Jammu and Kashmir, KA—Karnataka, KL—Kerala, MH—Maharashtra, ML—Meghalaya, MN—Manipur, MP—Madhya Pradesh, MZ—Mizoram, NL—Nagaland, OD—Odisha, PB—Punjab, RJ—Rajasthan, SK—Sikkim, TN—Tamil Nadu, TR—Tripura, TS—Telangana, UK—Uttarakhand, UP—Uttar Pradesh, WB—West Bengal

are being used in Ayurveda, Unani, and Amchis systems of medicine. The plains of Ladakh, azure blue water bodies at Tso-moriri, and valleys of Lahaul and Spiti are some of the most beautiful landscapes in the cold desert. The ever-increasing human activities and overexploitation of natural resources are posing threats to this fragile ecosystem. A planned approach for sustainable development and to conserve this fragile ecosystem is the need of the hour, which can only be achieved by collective responsibility.

17.2.2.2 Hot Desert

The Thar Desert, also known as the Great Indian Desert, covers approx. 285,000 km^2, is situated in the arid western part of Rajasthan state in India and includes the adjoining sandy terrain of Pakistan until the Indus River. It forms a distinctive but integral part of the arid lands of western India that runs through the states of Punjab, Haryana, Rajasthan, and Gujarat. The flora of the Thar Desert is unique and is the living representative of races of plants that have undergone great evolutionary changes after entering the desert over a long period of time. The vegetation is quite sparse, consisting mainly of stunted, thorny, or prickly shrubs with a few scattered drought resistance trees and perennial herbaceous growth. The ephemeral herbaceous flora appears during the rainy season and completes its life cycle before the advent of winters.

17.2.2.3 White Salt Desert of Kutch

The Rann of Kutch is a salt marshy land in the Thar Desert in the Kutch district of western Gujarat. It lies between Gujarat in India and the Sindh province in Pakistan. It comprises around 30,000 km^2 of land, which includes the Great Rann of Kutch, the Little Rann of Kutch, and Banni grassland. The vegetation of Little Rann of Kutch is classified into Rann saline thorn scrub, Salvadora scrub, and Tropical Euphorbia scrub (degradation stage). The vegetation types present in semiarid are characterized according to their degree of salinity. The important floristic elements are *Prosopis cineraria*, *Capparis decidua*, *Zizyphus*, *Salvadora*, etc.

17.2.3 Grassland

Grasslands are multifunctional ecosystems that not only contribute to the livelihoods of a substantial population but also have major relevance in biodiversity conservation by protecting soil against erosion, wildlife habitat, carbon sequestration, and water harvesting in a landscape. These are the transitional landscapes dominated by grasses with few or no trees. In spite of the great ecological value, only 1.75% of the total forested area of India belongs to grassland ecosystems. The grassland ecosystem in the country is affected by severe degradation of natural forests, high biotic interference, excessive grazing, and land clearing for agriculture. The ecological conditions of grasslands in some areas have improved since the special Task Force for Grasslands and Deserts made fundamental changes in the planning and grazing policy for the country (Rawat and Adhikari 2015). The resource inventory system and ecological monitoring of grassland ecosystems are scanty and underestimated. Therefore, urgent attention is needed for the documentation of the grassland ecosystem status and trends on both a regional and national level. Based on the dominance of species, different grass community types have been described from India (Rawat and Adhikari 2015). The details of the type of grasslands classified in India are given in Table 17.2. In the present context, some of the important Indian grassland ecosystems and their floristic composition are discussed here.

17.2.3.1 Grasslands of Western Himalaya

Fragile alpine ecosystems of Western Himalaya are some of the unique biodiversity-rich landscapes in the Himalayas, which occur between snow and tree lines. These

Table 17.2 Grassland of India (adapted from Grassland vegetation of India: an update, Chandran 2015)

S. No.	Category and character	Subcategory		Dominated species	Distribution
1.	Coastal grassland	Grasslands of sea beaches	Mainland beaches	*Spinifex littoreus* *Trachys muricata* *Stenotaphrum dimidiatum*	Western and eastern tropical coastal area of India
			Inland beaches	*Thuarea involuta*	Andaman and Nicobar and Lakshadweep
		Salt marsh grassland		*Aeluropus lagopoides*, *Suaeda fruticosa*	Rann of Kachchh
		Mangrove grassland		*Myriostachya wightiana* *Zoysia matrella* *Sporobolus virginicus* *Halopyrum mucronatum* *Porteresia coarctata*	Bhitarkanika, Sunderbans, Pichavaram, East coast of Goa, Bombay, Calicut, Kadalundi, Payyannur
2.	Riverine alluvial grassland			*Saccharum spontaneum* *Saccharum bengalense*	All major alluvial beds of the rivers like Ganga in Northern India, Bhramputra in Eastern India, Mahandi, Godavari, Narmada Cauvery, Krishna in peninsular India
3.	Montane grasslands	Himalayan sub-tropical grasslands		*Chrysopogon fulvus* *Arundinella nepalensis* *Pennisetum orientale* *Apluda mutica* *Heteropogon contortus*	Southern slopes of Himalaya between 1000 and 1800 m
		Himalayan temperate grasslands		*Chrysopogon gryllus* *Andropogon munroi* *Themeda anathera* *Saccharum rufipilum*	Himalayan mountain slopes between 1800 and 3000 m
		Alpine meadows/ Bugyals/Marg		*Danthonia cachemyriana*, *Danthonia cachemyriana*, *Festuca* spp., *Agrostis pilosula*, *Koeleria argentea*, *Phleum alpinum*, *Poa annua*	Southern face of the Himalaya above an altitude of 3000 m and up to 5200 m altitude. J & K; Himachal Pradesh, Uttarakhand, Sikkim, and Arunchal Pradesh
		Trans-Himalayan steppes		*Elymus nutans* *Leymus secalinus* *Kobresia* spp. *Catabrosa aquatica*	Northern face of Trans-Himalaya, above 4000 m. Ladakh, Lahul, Spiti, Kinnaur, Nilang, Malla, Lapthal, Niti of

(continued)

Table 17.2 (continued)

S. No.	Category and character	Subcategory		Dominated species	Distribution
					Uttarakhand, and Tso Lhamu of Sikkim
		Grasslands of the North East Hills		*Festuca*, *Bromus*, *Arundinella*, *Agrostis*, *Cyathopus*, *Coix*, *Tripsacum*, *Cymbopogon*, *Themeda villosa* *Microstegium*, *Glyceria*, *Gymnopogon*	Sub-tropical to temperate region of North Eastern Hill states, Dzukou valley in Nagaland and Ukhrul Grassland of Manipur, Saramati grassland of Nagaland
		Grasslands of Central Highlands		*Manisuris forficulata*, *Arthraxon*, *Pennisetum*, *Diectomis*, *Schizachyrium*, *Cymbopogon*, *Themeda*, *Eragrostis*	Central Indian highlands viz., Vindhyas and Satpuras
		Western Ghats	Plateaus of North Western Ghats	*Dimeria*, *Ischaemum*, *Manisuris*, *Arthraxon*, *Heteropogon*, *Arundinella*, and *Jansnella*	Karnataka, Goa, and Maharashtra
			Shola grasslands	*Eulalia phaeothrix*, *Dichanthium polyptychum*, *Chrysopogon hackelli*, *Chrysopogon*	High altitude grasslands of the Western Ghats having an altitude of above 1800 m
			South Western Ghats	*Spodiopogon rhizophorus*, *Garnotia*, *Zenkeria*, *Arundinella*, *Pennisetum polystachyon*, *Vetiveria lawsonii*, *Ischaemum zeylanicolum*	Wayand and Idduki district of Kerala
		Eastern Ghats		*Arundinella setosa*, *Aristida adscencionis*, *Heteropogon contortus*, *Sporobolus*, *Themeda*, *Chrysopogon*	Eastern Ghats: Yercaud, Javadi hills, Malkana Giri around 700 m altitude
		Montane bamboo brakes		*Arundinaria densiflora*, *Arundinaria hirsute*, *Yushania anceps*	Khasi Hills of Meghalaya, Dzukou bamboo belt of Nagaland, and some subalpine region of Uttarakhand
4.	Sub-Himalayan Tall Grasslands of Terai region			*Narenga porphyrocoma*, *Saccharum bengalense*,	Foothills of Gangetic basin and naturally irrigated belt. Jammu

(continued)

Table 17.2 (continued)

S. No.	Category and character	Subcategory	Dominated species	Distribution
			Saccharum spontaneum, *Erianthus ravennae*, *Phragmites australis*, *Arundo donax*, *Cymbopogon flexuosus*	Kashmir to Uttar Pradesh, Assam West Bengal, and Arunachal Pradesh
5.	Tropical Savannas	Desert savannas	*Lasiurus*, *Scindicus*, *Aristida* spp., *Sehima nervosum, Cenchrus biflorus, Stipa grostisplumosa*	Great Indian Thar Desert/Hot Desert of Rajasthan
		Tropical savannas of peninsular India	*Sehima nervosum*, *Dichanthium annulatum*, *Dichanthium annulatum*, *Bothriochloa*, *Cymbopogon*, *Triplopogon ramossissimus*, *Dimeria*, and *Eulalia*	Deccan plateau and Western India. Saurashtra in Western Gujarat; Deccan plateau of Karnataka, and Maharashtra
		Northern tropical hill savannas	*Chrysopogon fulvus*, *Neyraudia arundinacea*, *Arundinella bengalensis*, *Aristida cyanantha*, *Heteropogon contortus*, *Imperata cylindrical*, and *Aristida adscencionis*	Tropical area of Northern India, Aravali, Shiwaliks hills, and Sub-Himalayan foothills
		Closed Sal forest grasslands	*Narenga porphyrocoma*, *Cymbopogon flexuosus*, *Themeda arundinacea*, *Desmostachya bipinnata*, *Dichanthium annulatum*, *Bothriochloa bladhii*, *Imperata cylindrica*, *Chloris dolichostachya*	Sal forest belt of sub-Himalaya and Central India
6.	Wet grasslands		*Phragmites australis*, *Arundo donax*, *Erianthus ravennae*, *Saccharum spontaneum*, *Ischaemum indicum*,	Semi-aquatic and wet grassland area of sub-Himalaya

(continued)

Table 17.2 (continued)

S. No.	Category and character	Subcategory	Dominated species	Distribution
			Echinochloa crus-galli, *Panicum repens*, *Eriochloa procera*, *Leersia hexandra*, *Sacciolepis interrupta*, *Hymenachne acutigluma*, *Oryza rufipogon*	

alpine pasture lands or meadows above the tree limits are used as alpine pasture for grazing cattle during summer months and are locally called "*Bugyal* or *Khark*" (Uttarakhand), "*Thaach*" (Himachal Pradesh), and "*Margs*" (Jammu and Kashmir) and play an important role in the socio-economy status of inhabitants (Rawat 2005). The alpine and subalpine meadows in the inner valleys of Kashmir are locally known as "margs." These grazing pastures are above the tree line and below the snow line and are dominated by grasses like *Danthonia cachemyriana*, *Stipa concinna*, S. *orientaila*, *Poa aniwa*, *P. stewartiana*, *Elymus himalayanus*, *E. longi-aristatus* subsp. *canaliculatus*, *Agrostis munroana*, *Calamagrostis decora*, *C. emodensis*, *Dactylis glomerata*, and others. *Kobresia duthiei* and *K. nepalensis* are the common Cyperaceae plants found along with the grasses in these pasture lands. These alpine zones remain covered with snow in the winter months but come to life with colours at the advent of the summer season. The aboveground biomass is observed maximum during July–August due to the accumulation of food material in winter and translocation of the same in the growing season to aboveground parts (Mishra 1968). The aboveground biomass declined after September due to the lowering of temperature and permafrost.

17.2.3.2 Grassland of Saurashtra and Kachchh

The scrub savannah ecosystem or the degraded dry grassland of Saurashtra and Kachchh are characterized by the presence of a number of annual grass communities of *Andropogon pumilius*, *Arundinella setosa*, *Brachiaria eruciformis*, *Brachiaria ramose*, *Cenchrus ciliaris*, *Heteropogon contortus*, *Iseilema prostratum*, *Panicum turgidum*, *Dichanthium annulatum*, *Sporobolous verginicus*, *Tragus biflorus*, *Bothriochloa ischaemum*, etc. The grasslands locally known as "Vidis" in Saurashtra cover a total area of 1810 km, contributing 20.08% to the total grassland cover of Gujarat state. These grasslands not only have great ecological significance in stabilizing the soil but also are the main sources of fodder for the cattle rearing communities of Saurashtra and Kachcch (Sugoor and Ande 2001). Apart from Saurashtra and Kachcch, a considerable part of Jamnagar, Surendranagar, Bhavnagar, Dhari, Gir East, Barda Wildlife Sanctuary, Jungadh, and Gir West wildlife division are also represented by this type of grasslands. The main grassland communities found in this region are *Schima–Dichanthium* type, *Schima–Aristida* type, *Heteropogon–Cymbopogon* type, and *Bothriochloa–Aristida* communities dominating in dry hillocks and heavily disturbed areas and *Cenchrus–Dichanthium, Eragrostris–Aristida*, and *Aeluropus–Halopyrum–Urochondra* communities dominating in sandy soils and mild grazing areas. Other than grasses, scattered growth of mostly thorny species, such as *Acacia nilotica*, *A. senegal*, *A. catechu*, *A. leucophloea*, *Zizyphus nummularia*, *Commiphora wightii*, *Maytenus emarginata*, *Balanites aegyptica*, and *Euphorbia* spp., are found in many Vidis (Mehta 2016). In some Vidis, especially of the Junagadh division along with the thorny species, *Boswellia serrata*, *Butea monosperma*, *Bauhinia purpurea*, *Terminalia crenulata*, and *Diospyros melanoxylon* are also present. Along with these, *Asparagus racemosus*, *Dalechampia scandens*, *Rynchosia minima*, *Phyllanthus racemosus*, and *Cardiospermum halicacabum* are the main climbers in the Vidis of Saurashtra.

17.2.3.3 Tree Savannah Forest Ecosystems

Savannah vegetation is also quite extensive in the subtropical region of Northwestern Himalaya. These grasslands are not climax type but are constantly maintained by prescribed burning and regular harvesting. The grassland appears wherever clear-felling has been done in deciduous forests and thus one can commonly notice *Bombax ceiba*, *Shorea robusta*, and *Lannea coromandelica* in these grasslands and hence termed as “tree savannah” in comparison with “shrub savannah,” which are common in the foothills of Eastern Himalaya (Hajra and Vohra 1996). The dominant grasses in these savannahs are *Apluda mutica*, *Arudinella* spp., *Imperata cylindrica*, *Themeda* spp., *Saccharum* spp., etc. and are of high fodder value. Shrubby species such as *Flemingia fruticosa*, *Clerodendrum* sp., and several legumes and composite members grow abundantly mixed with the grasses, especially after rains. This type of vegetation is common around the foothills region of Uttar Pradesh and Himachal Pradesh.

Another typical form of dry savannah forest formed because of intensive biotic interferences, like burning, lopping, and grazing, is seen scattered throughout the Eastern Ghats. These are mostly seen in the hilltop areas with an altitudinal range of around 100 m. Here, the trees stand far apart singly or in small groups in heavy grass in which certain fire-resistant plants persist. The trees have short boles and are usually crooked and unsound or hollow. Stemless *Phoenix humilis* var. *pedunculata* is particularly characteristic of these forests.

17.2.3.4 Tropical Riverine Grasslands of North Bengal and Northeast

In the foothills of Mikir hills, Darjeeling, and Kalimpong areas of North Bengal, a sub-climax type of grassland is found due to combined effects of frequent heavy floods, forests fire, indiscriminate felling of trees, and overgrazing. Similarly, the extensive grasslands of Kaziranga, Coach Behar, and Jalpaiguri districts are an edaphic climax combined and influenced by floodwaters of Brahmaputra, Teesta, and their tributaries. The dominant grasses in these grasslands are *Arundinella bengalenis*, *Axonopus compressus*, *Chrysopogon aciculatus*, *lmperata cylindrica*, *Neyraudia ryaudiana*, *Panicum atrosanguineum*, *P. khasianum*, *Pennisetum glaucum*, *Phragmites australis*, *Saccharum* spp., *Thysanolaena maxima*, and *Vetiveria zizanioides* and provide a suitable habitat for *Rhinoceros unicomis.* In Meghalaya, Manipur, and Nagaland, the species are replaced with *Agrostic micrantha*, *Brachypodium sylvaticum*, *Coelorachis striata*, *Cymbopogon khasianus*, *Eragrostis nigra*, and *Phacelurus zea*, which are extensively used as fodder and fetch direct monitory benefits to the local inhabitants.

17.2.3.5 Shola Forest of Western Ghats

These are unique ecosystems of Southern montane wet grasslands (Shrub Savannah) occurring above 1600 m elevation in the Nilgiris plateau of southern Western Ghats. These grasslands are distributed all over the range, but their composition, size, and height of the associated trees vary according to altitude and the velocity of the wind. The dominating communities of *Chrysopogon zeylanicus–Arundinella* spp. type and *Andropogon polyptychus–Eulalia phaeothrix* type of grassland occur above 1800 m elevation. The main associated forage species are *Andropogon lividus*, *Arundinella purpurea*, *A. serosa*, *Bothrichloa insculpta*, *Eragrostis nigra*, *Ischaemum indicum*, and *Tripogon bromoides*. A large number of shrubby and herbaceous species *Anaphalis neelgerryana*, *Heracleum hookerianum*, *Leucas rosmarinifolia*, *Pleocaulus sessilis*, and *Senecio polycephalus* occur here along with the woody *Rhododendron arboreum* ssp. *nilagiricum*, *Ligustrum perrottetii*, and *Syzygium calophyllifolium* above 2400 m elevation (Vajravelu and Vivekandan 1996).

17.2.3.6 Grasslands of Central Highlands

These grasslands are found in the Central Indian highlands, viz., Vindhyas and Satpuras, and are mainly found intermixed with tropical dry deciduous forests on rocky patches. The grasslands on the steep slopes of the Vindhyan ranges are dominated by *Tripogon jacquemontii*, which is found drooping down the slopes. The plateaus of Satpura ranges, especially the Pachmarhi plateau, have several types of grasses forming large patches belonging to several species of *Apluda*, *Aristida*, *Arthraxon*, *Chloris*, *Cymbopogon*, *Cynodon*, *Dichanthium*, *Diectomis*, *Digitaria*, *Dimeria*, *Eragrostis*, *Pennisetum*, *Sporobolus*, *Themeda*, and *Vetiveria.* Other elements dominating the herbaceous flora belong to several families like Leguminosae, Malvaceae, Rubiaceae, Scrophulariaceae, Asteraceee, Boraginaceae, Convolvulaceae, Commelinaceae, Eriocaulaceae, and Cyperaceae (Verma 1996).

17.2.4 Wetland Ecosystems

India harbours diverse types of wetlands. As per the current estimates, India has a total wetland area of 15.26 m ha, accounting for nearly 4.7% of the total geographical area. The inland–natural wetlands accounted for around 43.4% of the total area, while the coastal–natural wetlands accounted for 24.3%. Among the 19 wetland types, river/stream is the dominant one, occupying 5.26 m ha area, while the two coastal/marine wetland categories, namely coral reefs and mangroves, occupy 142,003 and 471,407 ha, respectively (Panigrahy et al. 2012). With vast stretches of intertidal mudflats and salt pans, Gujarat ranks first at 22.77% (3.47 m ha) of the total wetlands of India, followed by Andhra Pradesh (1.45 m ha), Uttar Pradesh (1.24 m ha), West Bengal (1.11 m ha), and Maharashtra (1.01 m ha). Tamil Nadu has the highest number of lakes (4369), followed by Uttar Pradesh (3684) and West Bengal (1327) (Panigrahy et al. 2012). West Bengal has the highest area under mangrove (209,330 ha), followed by Gujarat (90,475 ha) and Andaman and Nicobar Islands (66,101 ha). Coral reefs are observed in Lakshadweep (55,179 ha), Andaman and Nicobar Islands (49,378 ha), Gujarat (33,547 ha), and Tamil Nadu (3899 ha). Jammu and Kashmir have the highest share of high-altitude wetlands accounting for 87.24% area with 2104 lakes, followed by Arunachal Pradesh with 1672 lakes contributing 9.4% of the area (Panigrahy et al. 2012).

Depending upon the duration of waterlogging, the aquatic ecosystems support diverse communities of biota representing almost all taxonomic groups. The aquatic (and wetland) flora can be classified into free-floating hydrophytes, suspended submerged hydrophytes, anchored submerged hydrophytes, submerged hydrophytes with floating leaves, emergent amphibious hydrophytes, etc. The total numbers of aquatic plant species exceed 1200, as reported from the wetland system of India (Gopal and Sah 1995). The high species diversity of these wetlands provides many services continuously such as food, fodder, and commodities to humanity. Besides playing a crucial role in the hydrological cycle, wetlands are the most productive ecosystems in the world and a potential source of carbon sequestration. Ecological degradation and water pollution are the major threat to the wetland ecosystems and have led to a loss of ecosystem services, which can significantly weaken the capability of wetlands to provide ecosystem services, posing serious risks to food production, the water supply, and biodiversity resources (Lu et al. 2011).

17.2.4.1 Mangrove Ecosystems

Mangroves produce one of the richest ecosystems by regulating the flow of water laden with rich organic minerals, stabilizing the alluvial soil brought from the river systems, and fixing the sediments of the sea with the detritus. Mangroves also function as a buffer against the oil slicks washed down from the sea. They are of economic importance, being a source of timber, fuel, etc., and providing a good breeding ground for fishes and other aquatic animals. Mangroves, besides acting as

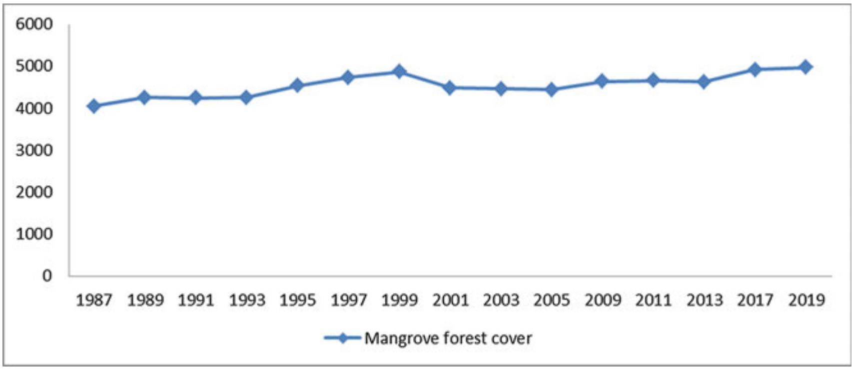


Fig. 17.4 Changing trend of mangrove forest in last two decades (Source: Compiled from FSI Reports 1985–2019)

stabilizers of wind and sea wave action along with the coastal belts, also help dissipate the wave energy (Banerjee et al. 1989). Typical mangroves are plants that have partly reached the sea estuarine interphase on stilts or props with adaptations like viviparous germination and pneumatophores for survival in the partly saline and partly submerged coastal ecosystems (Rao and Banerjii 1982).

India has a mangrove forest cover of 4975 km^2, occupying only 3.2% of global mangrove forest and 0.15% of the total geographical area of India. Sundarbans have the largest mangrove cover, occupying 42%, and Gujarat has the second-largest cover with 23% of total cover in India. Over the past three decades (1987–2019), the mangrove forest cover has increased by 912 km^2, i.e., 22.8% over 30 years (Fig. 17.4). The very dense mangrove comprises 1476 km^2 (29.66% of the mangrove cover), moderately dense mangrove is 1479 km^2 (29.73% of the mangrove cover), while open mangroves cover an area of 2020 km^2 (40.61% of the mangrove cover) (Forest Survey of India 2019).

India is the third richest country for mangrove biodiversity in the world, after Indonesia and Australia (Ragavan et al. 2016). Bhitarkanika in the Odisha state is considered the "mangrove genetic paradise" in the world and is associated with the largest population of birds and crocodiles, especially albino crocodiles. India has the highest record of biodiversity in mangrove forests of the world, and no other countries have recorded so many species to be present in the ecosystem. So far, 4107 species including 23% of flora have been recorded (Kartiseran 2018). Mangrove vegetations often exhibit two growth forms, namely scrubs and trees. *Avicennia alba* and *A. marina* stretch long areas in the form of scrub forests while *Rhizophora mucronata* forms tree layer in tidal ecosystems. If swampy conditions prevail, they form a dense growth and attain considerable growth size with compactly packed pneumatophores and stilt roots all over. Some of the common plants of mangrove ecosystems are *Avicennia alba*, *A. marina*, *A. officinalis*, *Aegiceras comiculatum*, *Bruguiera gymnorrhiza*, *Ceriops decandra*, *Kandelia candel*, *Xylocarpus molnuccensis*, *Rhizophora apiculata*, and *R. mucronata.* Common species found in Sunderbans are *Heritierafomes*, *Rhizophora* spp., *Kandelia candel*, *Avicennia alba*, *Bruguiera conjugata*, *Ceriops tagal*, *Lumitzera racemosa*, *Xylocarpus granatum*, *Ceriops roxburghiana*, *Sonneratia apetala*, etc.

The mangroves on the east coast (57% of the total) are the largest in India, which are not only attained good sociability, density, and stature but also are composed of a relatively good number of species. The west coast mangroves (30%) are poor in quality and quantity. The major estuaries on the Coromandel coast are Mahanadi estuarine complex (about 30,000 acres), Godavari (about 33,260 acres), Krishna (about 12,800 acres), and the shallow Cauvery estuarine (about 6660 acres) systems, and they have more than 88% of the total mangrove species of India, while the west coast estuarine ecosystems contribute about 62% of total species. Almost 44% of species are common in both east and west coasts. The distribution of some mangrove species is habitat-specific: *Aegialitis rotundifolia*, *Nypa fructicans*, *Phoenix paludosa*, *Porteresia coarctata*, and *Urochondra setulosa. Aegialitis rotundifolia*, an erect shrub, is confined only to the tidal bank of Sunderbans and Mahanadi delta. *Nypa fruticans* constitutes a gregarious group wherever it is found in the estuarine and brackish swamps of the Gangetic Sundarbans (Table 17.3).

17.2.5 Agro-ecosystems

Based on the edaphic, climatic, and geographic characteristics, cropping pattern, growing periods, and crop compositions, the National Bureau of Soil Survey & Land Use Planning (NBSS & LUP) have recognized 20 distinct agro-ecosystems in India (Table 17.4). India is one of the 12 centers/regions of diversity of crop plants in the world (Zeven and de Wet 1982). Traditional agriculture practices of India have played a major role in the diversification of crop resources in this region. The estimated strength of wild relatives of crop plants and the related taxa occurring in India is about 320 species (Arora and Nayar 1984). Rich genetic diversity occurs in several crop plants and their wild progenitors. In the diverse agro/eco-climate, this region is aptly called “Hindustani Centre” of origin of crop plants. Out of the 329.2 million ha. of land, the semiarid agro-ecosystems contribute 44.3% of the total, followed by subhumid ecosystems (27.2%), arid ecosystems (13.6%), humid per-humid ecosystems (8.6%), and coastal ecosystems (6.4%) (Mandal et al. 2018).

Table 17.3 Mangrove wetlands of India and its dominant species

State/UT	Mangrove cover in km^2 (% total area)	Change of cover in last two decade	Dominant species and associated
Andhra Pradesh	404	−18.38	*Excoecaria agallacha*, *Avicennia officinalis*, and *Sonneratia apetala*
Andaman and Nicobar	616	−10.05	*Heritiera fomes*, *Kandelia candel*, *Avicennia alba*, *Bruguiera conjugata*, *Xylocarpus molnuccensis*, *Ceriops tagal*, *Lumitzera racemosa*, *Xylocarpus granatum*, *Ceriops roxburghiana*, *Sonneratia apetala*
Gujarat	1177	+167.98	*Ceriops tagal*, *Excoecaria agallocha*, *Kandelia candel*, *Lumnitzera racemosa*, *Rhizophora apiculata*, *Sonneratia caseolaris*
Maharashtra	320	+117.14	*Aegiceras comiculatum*, *Avicennia alba*, *Bruguiera cylindrica*, *B. gymnorrhiza*, *Cerbera manghas*
Odisha	251	+22.11	*Excoecaria agallacha*, *Ceriops decandra*, and *Sonneratia apetala*
West Bengal	2112	+1.83	*Excoecaria agallacha*, *Ceriops decandra*, and *Sonneratia apetala*
Goa	26	+2600	*Avicennia marina*, *A. officinalis*, *Rhizophora mucronata*, and *Sonneratia alba*
Kerala	9	+900	*Avicennia officinalis*, *Barringtonia racemosa*, *Bruguiera gymnorrhiza*, *Ceropegia tuberosa*
Daman and Diu	3	+300	*Bruguiera gymnorrhiza*, *Excoecaria agallocha*
Karnataka	10	+1000	*Cynometra iripa*, *Heritiera littoralis*, *Sonneratia caseolaris*
Tamil Nadu	45	+113	*Aegiceras corniculatum*, *Avicennia alba*, *Bruguiera gymnorrhiza*, *Lumnitzera racemosa*, *Rhizophora mucronata*, and *Sonneratia apetala*
Puducherry	2	+2	*Bruguiera gymnorrhiza*, *Lumnitzera racemosa*
Total	4975	21.63	

Table 17.4 Agro-ecological zones of India and their characteristics

Agro-ecological region	Area includes	Characteristics	Major crops
Arid ecosystem (13.6%)			
Western Himalayas	Eastern and western aspects of Ladakh Plateau	Western Himalayas, cold arid ecoregion with shallow skeletal soils and LGP <90 days	Millets and barley (North Kashmir Himalayas)
Western Plain, Kachchh, and part of Kathiwara Peninsula	Rajasthan, North Gujarat plain and Southwestern Punjab plain, Kachchh, and North Kathiawar Peninsula	Hot arid ecoregion with desert saline soils and LGP <90 days (inclusion of 90–120 days)	Millets and pulses (Bagar)
Deccan plateau	Karnataka plateau	Hot arid ecoregion with mixed red and black soils and LGP 90–120 days	Millets, cotton, and oil seed
Semiarid ecosystem (44.2%)			
Northern plain and central highlands including Aravallis	Central highlands, North Punjab plain, Ganga-Yamuna Doab and Rajasthan upland, Gujarat plain, Rohilkhand and Avadah plain, Madhya Bharat plateau, and Bundelkhand uplands	Semiarid to subhumid ecoregion with coarse loamy alluvial soils (sandy loam to sandy clay loam) and LGP 90–150 and 150+ days	Millets, wheat, pulses, maize, sugarcane, and cotton
Northern plains, Gujarat plains	Uplands of Rajasthan, Northern Gujarat Plains, Madhya Pradesh plateau	Hot semiarid ecoregion with old alluvial soils and LGP 120–150 days (inclusion of 90–120 days)	Millets, wheat, and pulses
Northern plains	Middle Gangetic plain	Hot semiarid to subhumid ecoregion with alluvial and Tarai soils and LGP 150–180 days (inclusion of 120–150 days)	
Deccan Plateau	Coastal and Central Kathiawar peninsula, Kathiawar Peninsula Western Malwa Plateau, Eastern Gujarat plain	Hot, semiarid ecoregion with moderately deep black soils (inclusion of shallow soils) and LGP 120–150 days (inclusion of 150–180 days and 90–120 days)	Millets, cotton, pulses, and sugarcane
Deccan Plateau	Central, Eastern and Western Maharashtra plateau, North and Western Karnataka plateau, Northwestern Telangana humid; plateau, North Sahyadris	Hot semiarid ecoregion with mixed red and black soils and LGP 150–180 and 120–150 days	
Deccan (Telengana) plateau and Eastern ghats	Telengana region, North and South Telangana plateau, Eastern ghats	Hot semiarid ecoregion with red loamy soils and	Millets, oilseeds, rice,

(continued)

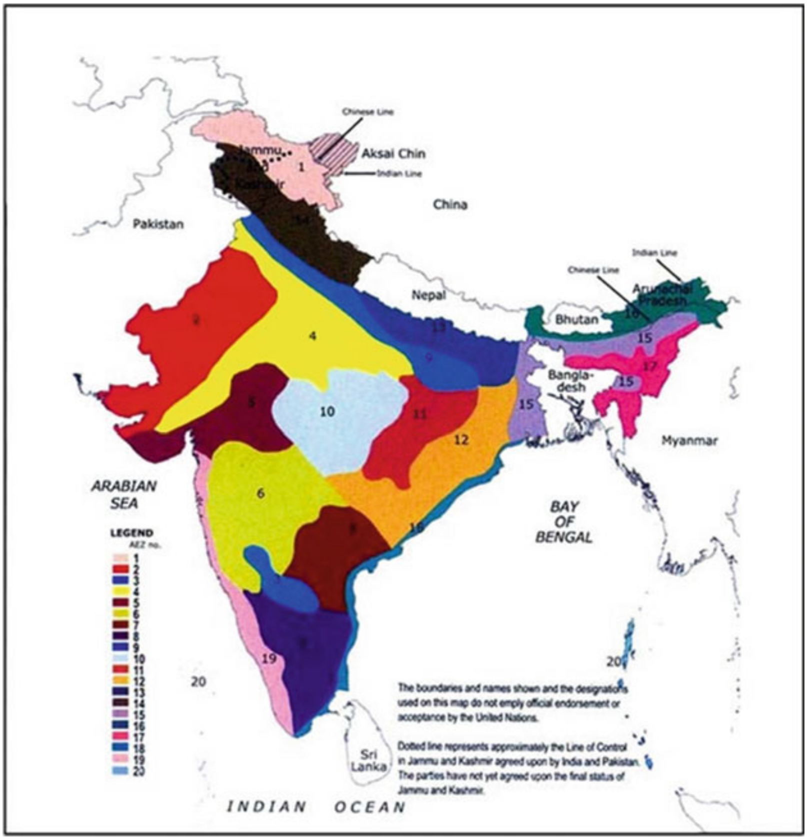
Table 17.4 (continued)

Agro-ecological region	Area includes	Characteristics	Major crops
		LGP 150–180 (inclusion of 180–210 days)	cotton, and sugarcane
Subhumid ecosystem (27.2%)			
Eastern plateau, Satpura range	Vindhyan and Satpura range and Narmada Valley, Mahanadi basin	Hot subhumid ecoregion with moderately deep black soils (inclusion red soils) and LGP 150–180 days (inclusion of 120–150 days)	Oilseeds, rice, cotton, and sugarcane
Eastern plateau, central highlands (Malwas, Budelkhand, and Eastern Satpura)	Malwa and Bundelkhand, Malwa plateau, Vindhyan Scarpland and Narmada valley, Satpura range and Eastern Vindhyan, Narmada valley, eastern Satpura range	Ecoregion with red and yellow soils and LGP 150–180 days (inclusion of 120–150 days)	Sorghum and pulses
Eastern plateau (Chattisgarh), Hot SubHumid ecoregion	Chhattisgarh/Mahanadi Basin, Dandakaranya and Eastern ghats, Chhotanagpur plateau	Hot subhumid ecoregion with red and lateritic soils and LGP 180–210+ days (inclusion of 150–180 days)	Rice, millets, and wheat
Northern plain, lower Gangetic plain	Punjab, Rohilkhand, Avadh, and south Bihar plains	Hot, subhumid ecoregion with alluvial soils (calcareous) and LGP 180–210 days (inclusion 150–180 days)	Pulses and sugarcane
Western Himalayas	South Kashmir, Himachal Pradesh, Punjab, and Kumaun Himalayas	Warm to hot subhumid to humid ecoregion sub-montane shallow and skeletal hill soils and LGP 120–150 and >210 days	Wheat, millets, maize, and rice
Bengal and Assam plains	Middle, Lower, and Upper Brahmaputra Plain, Bengal basin, North Bihar plain, Teesta, Barak valley	Hot/warm moist subhumid/ humid; alluvium-derived soils; GP 210 + days	Rice, jute, and plantation crops
Humid perhumid ecosystem (8.6%)			
Eastern plain	North Bihar, North Bengal plains, and Avadh plains, Foothills of Central Himalayas	Warm humid to prehumid ecoregion with alluvial soils and LGP >210 days	Rice, wheat, and sugarcane
Eastern Himalayas	Bhutan foot-hills, Darjeeling and Sikkim Himalayas, Arunachal Pradesh, Manipur, Mizoram, Tripura	Warm prehumid ecoregion with shallow and skeletal red soils and LGP >210 days	Rice and millets

(continued)

Table 17.4 (continued)

Agro-ecological region	Area includes	Characteristics	Major crops
North Eastern hills (Purvanchal)	Meghalaya Plateau, Nagaland Hill, Purvachal	Warm prehumid ecoregion with red and yellow soils and LGP >210 days	Forest and rice in patches
Coastal ecosystem (6.4%)			
Eastern Coastal plain island of Andaman and Nicobar	South and North Tamil Nadu plains (Coastal), Andhra plain, Utkal plain, East Godavari delta, Gangetic delta, Andaman and Nicobar Group of Islands	Hot subhumid (with humid to prehumid inclusion) transitional zone with coastal and deltaic alluvial soils and LGP 150–210+ days	Rice, pulses, and millets
Western ghats and Coastal plain, Lakshadweep	Central, North, and South Sahyadris, and Konkan Coast, Karnataka and Kerala Coastal Plain, Lakshadweep, and Group of Islands	Hot humid to prehumid (inclusion of subhumid ecoregion) with red and lateritic and alluvium derived soils and LGP >210 days (inclusion of 180–210 days)	Rice, tapioca, coconut, and millets



17.3 Driving Mechanisms of Ecosystem Changes

Due to tremendous biotic pressure, anthropogenic disturbances such as agricultural expansion, and the development of infrastructures, the forest ecosystems on a national scale are fragmented state. The people living in about 1.73 lakh forest fringe villages are totally or partially dependent on their livelihood on these forests. Cattle population much above the carrying capacity, felling of trees for timber, unscientific collection of fuelwood, and NTFP resources are causing great damages to the forest. Eventually, all these activities have reduced the forest ecosystems to a degenerative land cover in a transitional manner from forest to woodland to grassland to cropland (Zou et al. 2006). With increasing altitude, the forest ecosystem is gradually stabilizing as anthropogenic factors reduce, with a characteristic increase of total tree density, total basal area, and regeneration (Rawat et al. 2018).

The macroeconomic policies have also affected the forest ecosystems. For example, mining activities have significant effects on forest degradation and ecological changes (Singh et al. 2012). A recent study of mining-driven deforestation covering over 300 districts points out that states that account for about 35% of India's forest cover—Odisha, Chhattisgarh, Madhya Pradesh, Karnataka, and Jharkhand—also produce large amounts of coal and iron (E-Green Watch n.d.). During the last three decades (between 1980 and 2019), a total of 1 million 500,000 hectares of forests have been diverted, out of which more than 500,000 hectares for mining, the rest for thermal power, transmission lines, dams, and other projects (Government of India 2009). However, India's policy of forest management has shifted from production-oriented to conservation-oriented management. India also aims to increase its carbon sinks through afforestation. The Indian forested area has increased over recent years due to the national policies of sustainable forest management and afforestation (Gupta et al. 2020).

Invasive weed, fragmentation, excessive agriculture expansion, overgrazing, aggressive land-use changes, habitat degradation, and inadequate coverage of grassland habitats within the protected areas are the major drivers of grassland ecosystem degradation (Rahmani 2005). The different drivers are site-specific, and the degradation of grasslands has caused great losses in ecosystem services. For example, in the northeastern states and Assam riverine plains, shifting cultivation, deforestation, and cropland abandonment are the major drivers behind the grassland degradation at decadal time scales (Uma Shankar et al. 2009). In Saurashtra, not only the fodder production decreases but also the population of bustards, floricans, blackbucks, etc., while in the high alpine region of Western Himalaya, degradation of grasslands drastically alters the ecosystem functions, composition, species richness and diversity, aboveground and underground biomass, other edaphic parameters, and the fertility level (Singh et al. 2015).

The problem of deteriorating of wetland ecosystem is influenced by many factors. The most common threats to wetlands are generally water scarcity, negative economic, changing biodiversity, and human intervention (Chatterjee et al. 2015). Declining water quality in wetlands is also an issue of concern that affects the biodiversity and ecological balance to different degrees (Bassi et al. 2014). The growth rate of around 22% of the population in India in the last five decades has exerted tremendous pressure on wetlands and flood plain areas to meet the water and food demand of the growing population. Over 276 major and 1000 medium irrigation projects in the last five decades (Central Water Commission (CWC) 2010), the rapid explosion of artificial water restoration structures without proper hydrological and economic planning has caused widespread loss and fragmentation of freshwater ecosystems (Kumar et al. 2008). Besides agricultural runoff of pesticides and fertilizers and industrial and municipal wastewater discharges, all of which cause widespread eutrophication, global climate change is also an important driver of loss and change in a wetland ecosystem. The driving mechanisms behind the changes in the forest, grassland, and wetland ecosystems are complex and involve various factors. Not only the natural factors play a major role, but also their intensity and human-induced factors, i.e., population growth, livelihood needs, and socio-economic development needs, are often regarded as the most prominent direct drivers of ecosystem change (Lu et al. 2011).

17.4 Conservation Scenario

India has taken significant steps for the conservation of its biodiversity. There are 903 Protected Areas (101 National Parks, 553 Wildlife Sanctuaries, 57 Conservation Reserves, and 4 Community Reserves, established under the Wildlife (Protection) Act 1972), covering a total area of 164,980.75 km^2 (5.02% of the total geographical area of the country) under the protected area network for in situ conservation (http://wiienvis.nic.in/Database/Protected_Area_854.aspx). Besides, India has also 18 biosphere reserves, 25 marine wildlife sanctuaries on the mainland, and 104 marine wildlife sanctuaries on the Islands (Table 17.5).

In addition to this, more than 71,027.10 km^2 area has also been designated for 50 tiger reserves, and 69,582.80 km^2 has been protected for 10 elephant reserves in the country. The count of Ramsar sites in India has increased now to 42, which covers a total area of 11,528.578 km^2. The goal of ecosystem conservation is for the long-term persistence of the biota in the system. There are two paradigms: community-based conservation (CBC) (Hulme and Murphree 2001) and protected area conservation (Bruner et al. 2001). Protected areas are essential to conserving species unable to coexist with humans. They also function as ecological baselines to monitor the effects of humans on their own ecosystems.

Table 17.5 Area protected under protected area network in India

Categories	Number	Area (km^2)	Coverage % of the country
National parks	101	40,564.03	1.23
Wildlife sanctuaries	553	119,756.97	3.64
Conservation reserves	83	3858.25	0.12
Community reserves	163	833.44	0.03
Protected areas	903	165,012.33	5.03

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Chapter 18
Faunal Diversity at Ecosystem Level in India: Dynamics and Status

Kailash Chandra and Devanshu Gupta

18.1 Introduction

India, with an area of 32,87,263 sq. km, is the seventh-largest country in the world, lying entirely in the northern hemisphere; the mainland extends between latitudes 8°4′ and 37°6′ north, longitudes 68°7′ and 97°25′ east (www.india.gov.in). The country represents two of the major realms, Indo-Malayan and the Palaearctic (high Himalayas), with a wide variety of landforms and climates, ending in habitats ranging from tropical to temperate and from alpine to Desert. The diverse and rich vegetation wealth in the country is due to various climatic and altitudinal variations coupled with diverse ecological habitats. With over 150,000 species of flora and fauna and a high level of endemism, distributed in varied ecosystems such as the Himalayas, hot and cold deserts, grassland, forests, freshwater, marine, estuarine, mangroves, seaweeds, seagrass, and coral reefs, the country is one of 17 globally identified megadiverse countries. The total forest cover is 7,12,249 sq. km, 21.67% of the geographical area (India State of Forest Report 2019). There are 16 major forest types and 221 minor forest types identified in the country (Champion and Seth 1968). Of them, 38.2% constitute tropical dry deciduous forests, 30.3% tropical moist deciduous forests, 6.7% tropical thorn forests, 5.8% tropical wet evergreen forests, 5.0% sub-tropical pine forests, and 4.3% alpine, sub-alpine, and moist alpine forests.

The country also has 15 different agro-climatic zones that determine and influence the nature of agrobiodiversity in these zones. Out of 36 globally identified biodiversity hotspots, four are represented in India: Himalaya (excluding Trans-Himalaya), Indo Burma (Northeastern India except Brahmaputra valley and Andaman group of Islands), Sundaland (Nicobar), and the Western Ghats and Sri Lanka (entire Western Ghats) (Myers 1988; Myers et al. 2000) (Fig. 18.1). Based on

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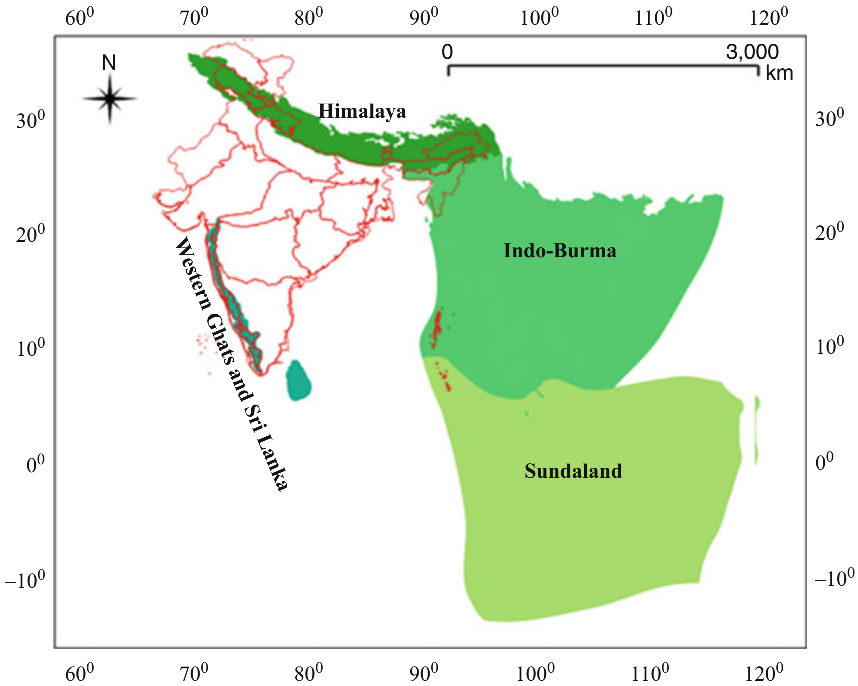


Fig. 18.1 Biodiversity hotspots in India

the uniqueness of similar ecology, biome representation, community, and species, India is divided into ten biogeographic zones: Trans-Himalaya, Himalaya, Desert, Semi-Arid, Western Ghats, Deccan Peninsula, Gangetic Plains, Northeast, Islands, and Coasts for each of the zones (Fig. 18.2; Rodgers and Panwar 1988; Rodgers et al. 2002). These bio-geographic zones are further differentiated into 27 biotic provinces representing specific communities separated by dispersal barriers or gradual changes in environmental factors. The Indian government has declared 987 Protected Areas (106 National Parks, 564 Wildlife Sanctuaries, 99 Conservation Reserves, and 218 Community Reserves) to protect its wild fauna. In addition to the above, 52 Tiger Reserves, 18 Biosphere Reserves, 32 Elephant Reserves, >7 Natural World Heritage sites, and 49 Ramsar Wetland Sites are also notified for the conservation of flagship species and various ecosystems. The total coverage of protected areas in India is 1,65,012.59 sq. km, covering about 5.02% of the country's forests (WII-ENVIS 2022). The country's floral diversity includes over 50,012 species, representing 12% of the global flora (Plant Discoveries 2019). This chapter summarizes India's faunal diversity in diverse ecosystems (terrestrial, freshwater, marine, estuarine, mangrove, soil, and agroecosystem) and ten biogeographic zones based on the Zoological Records, and published literature.

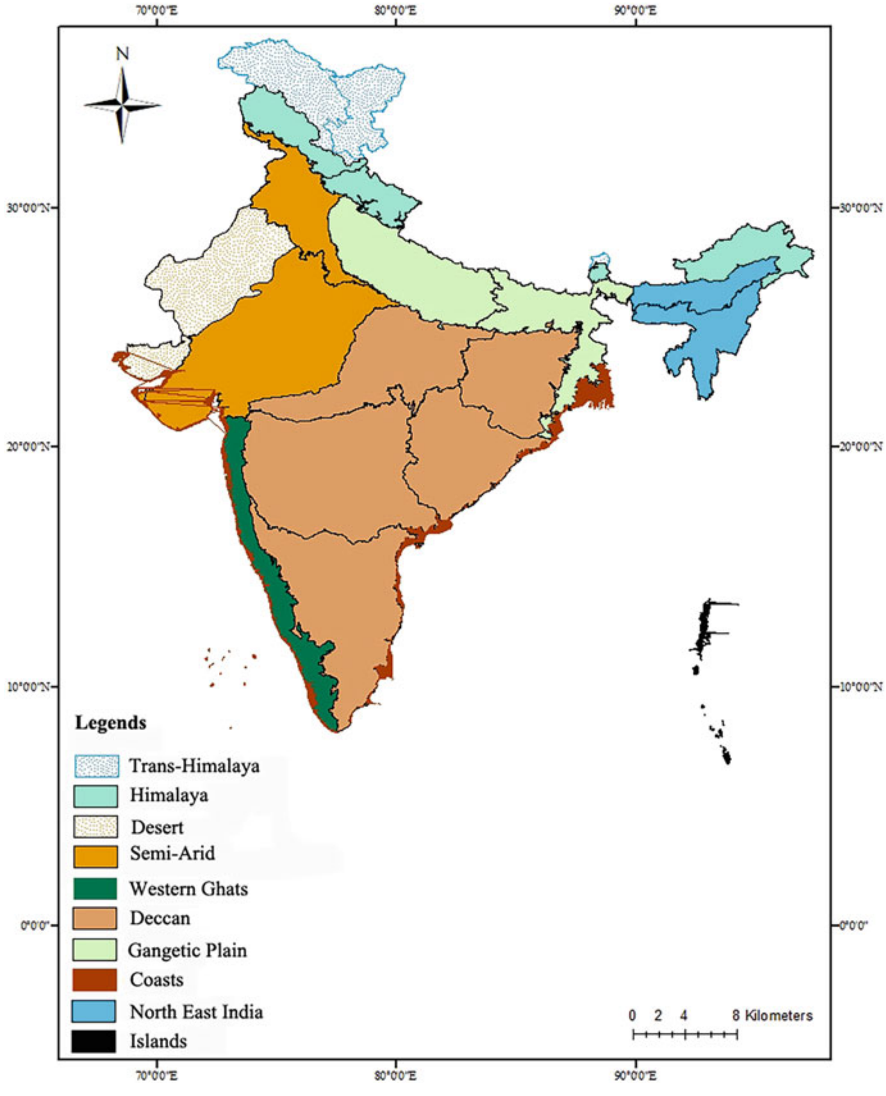


Fig. 18.2 Biogeographic zones of India (followed after Rodgers et al. 2002)

18.2 Faunal Diversity in India

As far as the country's overall faunal diversity is concerned, a total of 1,03,445 faunal species in different phyla of Animalia and Protista are so far reported from India (Table 18.1). The majority of the species (93,013) are invertebrates, followed by vertebrates with 6877 species and protozoans with 3545 species (Fig. 18.3). Of

Table 18.1 Faunal diversity of India (updated after Chandra et al. 2019a)

Kingdom	Phylum	World (living)	India
Protista	Phylum Protozoa	36,400	3545
Animalia	Phylum Dicyemida	122	10
	Phylum Porifera	8838	571
	Phylum Cnidaria	11,522	1459
	Phylum Ctenophora	199	20
	Phylum Platyhelminthes	29,487	1793
	Phylum Rotifera	2049	467
	Phylum Gastrotricha	828	163
	Phylum Kinorhyncha	196	10
	Phylum Nematoda	25,033	2990
	Phylum Acanthocephala	1330	307
	Phylum Sipuncula	156	41
	Phylum Echiura	198	47
	Phylum Annelida	17,388	1082
	Phylum Onychophora	183	1
	Phylum Arthropoda	12,57,040	77,560
	Subphylum Chelicerata	1,13,773	6120
	Class Arachnida	1,12,442	6082
	Class Merostomata	4	2
	Class Pycnogonidia	1335	36
	Subphylum Crustacea	67,735	3946
	Subphylum Hexapoda	10,63,533	67,111
	Class Collembola	8162	345
	Class Diplura	975	18
	Class Protura	816	20
	Class Insecta	10,53,578	66,728
	Subphylum Myriapoda	11,999	383
	Class Chilopoda	3112	101
	Class Diplopoda	7837	272
	Class Symphyla	204	10
	Phylum Phoronida	16	3
	Phylum Bryozoa (Ectoprota)	6186	338
	Phylum Entoprocta	186	10
	Phylum Brachiopoda	392	8
	Phylum Chaetognatha	170	44
	Phylum Tardigrada	1167	51
	Phylum Mollusca	84,978	5234
	Phylum Nemertea	1368	6
	Phylum Echinodermata	7550	784
	Phylum Hemichordata	139	14
	Phylum Chordata	71,526	6877
	Subphylum Cephalochordata	33	6

(continued)

Table 18.1 (continued)

Kingdom	Phylum	World (living)	India
	Subphylum Urochordata	2804	531
	Subphylum Vertebrata [= Craniata]	66,689	6350
	Class Pisces	34,362	3472
	Class Amphibia	7667	433
	Class Reptilia	10,450	670
	Class Aves	10,357	1345
	Class Mammalia	5853	430
	Total (Animalia)	**15,28,247**	**99,900**
Grand Total (Protista + Animalia)		**15,64,647**	**1,03,445**

India's total number of species in the table comprises the total number of species in different phyla (updated after Chandra et al. 2021e)

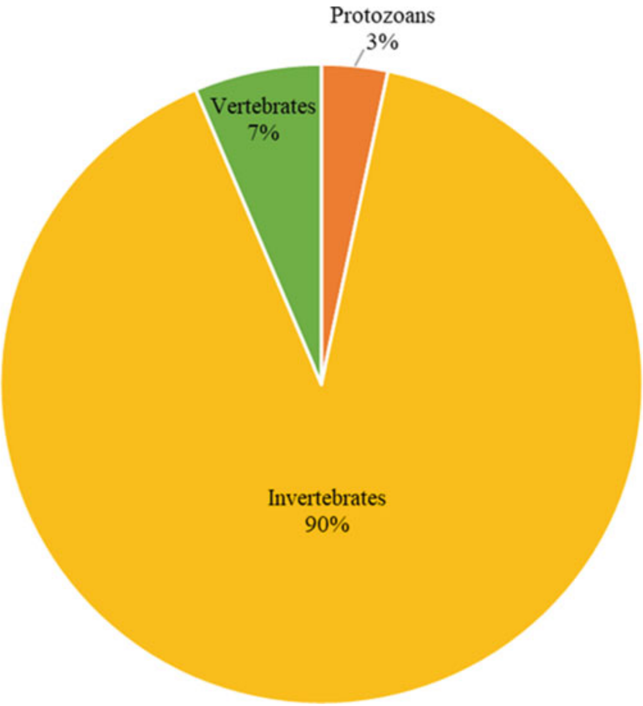


Fig. 18.3 Percentage representation of protozoans, invertebrates, and vertebrates in India

the overall fauna, about two-thirds of species (77,560) belong to the phylum Arthropoda, including 67,111 species of hexapods, 6082 species of arachnids, 3946 species of crustaceans, 272 species of millipedes, and 101 species of centipedes, 36 species of Pycnogonida, 10 species of Symphyla, and 2 species of

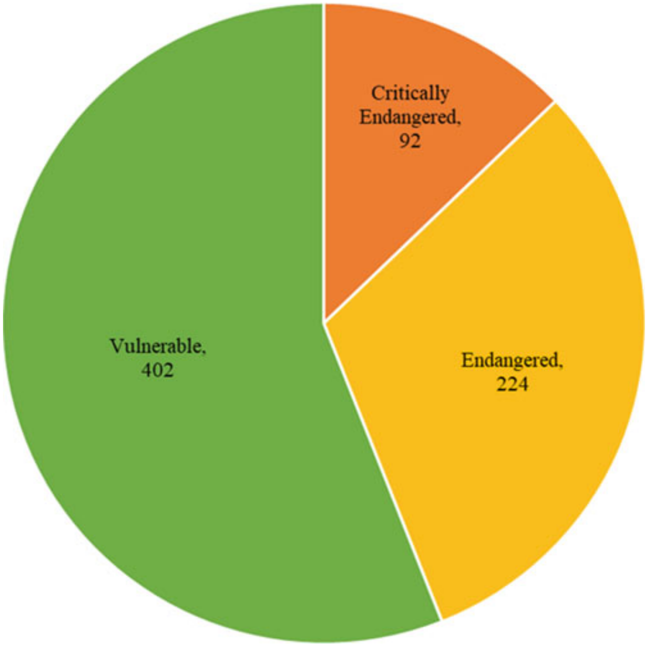


Fig. 18.4 Threatened fauna of India

Merostomata. As far as vertebrate diversity is concerned, there are 430 species of mammals, 1345 species of birds, 670 species of reptiles, 433 species of amphibians, and 3472 species of fishes for about 9.4% of the global vertebrate diversity (Table 18.1). Regarding India's threatened fauna, 718 species are threatened under IUCN Redlist-2021; of them, about 92 species are as Critically Endangered, 224 species as Endangered, and 402 species as Vulnerable (Fig. 18.4).

18.3 Biogeographic Zones

Biogeographically, the country is divided into ten different biogeographic zones: Trans-Himalaya, Himalaya, Desert, Semi-Arid, Western Ghats, Deccan Peninsula, Gangetic Plains, Northeast, Islands, and Coasts (Fig. 18.2) based on the uniqueness of similar ecology, biome representation, community, and species for each of the zones (Rodgers and Panwar 1988; Rodgers et al. 2002). Over 41% of the total geographical area of the country comes under Deccan Peninsula, 16.6% Semi-Arid, 10.79% Gangetic Plains, 6.56% Desert, 6.41% Himalaya, 5.62 Trans-Himalaya, 5.21% Northeast, 4.03% Western Ghats, 2.52% Coast, and the least area 0.25% under Islands. Even though the Deccan Peninsula includes the country's largest portion, fauna composition is represented by only 13.5% of the overall species

Table 18.2 Biogeographic zones of India with their respective area coverage and the number of faunal species

Biogeographic zone	Zone area (sq km)	Percentage area of India	Number of faunal species	Percentage of Indian fauna
Trans-Himalaya	1,84,823	5.62	3324	3.2
Himalaya	210,662	6.41	30,615	29.7
Desert	215,757	6.56	3346	3.2
Semi-Arid	545,850	16.6	7742	7.5
Western Ghats	132,606	4.03	17,099	16.6
Deccan Peninsula	1,380,380	41.99	13,911	13.5
Gangetic Plains	354,782	10.79	14,630	14.1
Coast	82,813	2.52	11,882	11.5
Northeast	171,341	5.21	18,527	18.0
Islands	8249	0.25	11,009	10.7

diversity (13,911 species; Table 18.2). Islands (Andaman and the Nicobar Islands) have only 0.25% of the country's total land area and have over 11,009 species, representing 10.7 of India's overall fauna. Compared to the area covered, the Himalayas comes to be the most diverse, with over 29.7% of Indian fauna known from this zone (Table 18.2). Trans-Himalayas (cold Desert) and deserts (hot Desert) have the same percentage of fauna, but species composition in these regions is uniquely different (Table 18.2).

18.4 Trans-Himalaya

Indian Trans-Himalaya (TH) is a unique and distinct area of the Himalayas, which lies in the north crest line of the great Himalaya and contains Zaskar and Ladakh ranges (Mani 1962) (Fig. 18.5). The region is usually termed a High Altitude Cold Desert and is characterized by low productivity, extreme aridity, reduced atmospheric pressure, low oxygen, extreme temperatures, high wind velocity, and high solar radiation intensity. Trans-Himalaya, with a total area of 1,84,823 sq. km, covers 5.62% of the country's landmass and is differentiated into three biotic provinces: Ladakh mountains (1A), Tibetan Plateau (1B), and Sikkim (1C) (Rodgers et al. 2002). Trans-Himalaya is an extension of the Tibetan Plateau on the northwest. It comprises the high altitude cold desert and arid mountain areas in Ladakh and Kargil (Jammu and Kashmir), Lingti plains (Lahaul Valley), and Spiti Valley of district Lahaul & Spiti. Cold deserts are also comprised of inner dry valleys of Pooh tehsil of district Kinnaur (Himachal Pradesh), small areas in the rain shadow of Nanda Devi range (Uttarakhand), and Kangchenjunga range (Sikkim) which are rain shadow zones between Higher Himalayan ranges (Mehta and Julka 2001). It also

Fig. 18.5 Indian Trans-Himalayan Landscape (Photo Credit: ZSI)

comprises a complex network of barren mountain ranges, lying in the north of the main Himalayan ranges, and includes Zaskar, Ladakh (5800 m), and Karakoram ranges (5500–6000 m) with an average elevation of 4000 m (Mani 1974).

Regarding the overall faunal diversity in TH, altogether 3324 faunal species have been recorded so far, representing about 10.9% of the total Indian Himalayan fauna (Table 18.3). Phylum Arthropoda with 2415 species represents approximately 72.7% of the TH faunal diversity (Table 18.3). There are over 100 species of mammals, 349 species of birds, 100 species of fishes, 16 species of reptiles, and 8 species of amphibians that have been recorded from the region. Though in the overall representation of Indian fauna, only 3.3% is represented in TH, the faunal elements are unique. They have evolved to endure the severities of extreme aridity, cold, diminished atmospheric pressure, and high solar radiation (Mehta and Julka 2001). Trans-Himalayas provide a suitable habitat for Apollo butterflies, are dominant, and have a maximum number of endemic species/subspecies in this region (Sidhu and Kubendran 2019). The wetlands of Ladakh have the distinction of being the only known breeding ground of Black-necked Crane in India (Chandan et al. 2008). The snow leopard is a large majestic carnivore distributed over most of the TH region. The main mammalian fauna present in the area includes snow leopard, Himalayan marmot, Blue sheep, Tibetan woolly hare, Tibetan gazelle, Himalayan ibex, Tibetan argali, Tibetan antelope, Ladakhurial, Tibetan wild ass, and wild yak (Namgail 2009; Habib et al. 2015; Kumar et al. 2017).

Table 18.3 Faunal diversity in biogeographic zones of India

Kingdom	Phylum	Trans-Himalaya	Indian Himalaya	Desert	Semi-Arid	Western Ghats	Deccan Peninsula	Gangetic Plains	Coasts	North East	Island
Protista	Phylum protozoa	17	372	69	220	375	512	522	702	243	276
Animalia	Phylum Mesozoa	–	–	–	–	–	–	–	6	–	–
	Phylum Porifera	–	6	6	9	23	5	16	453	5	153
	Phylum Cnidaria	–	2	2	3	–	2	13	901	4	976
	Phylum Ctenophora	–	–	–	–	–	–	–	16	–	3
	Phylum Platyherlminthes	11	250	92	151	330	264	582	647	230	57
	Phylum Rotifera	27	279	46	168	213	301	153	112	320	112
	Phylum Gastrotricha	01	1	–	–	–	–	–	40	6	18
	Phylum Kinorhyncha	–	–	–	–	–	–	–	9	–	5
	Phylum Nematoda	170	744	315	505	191		846	473	503	147
	Phylum Acanthocephala	01	37	7	34	–	39	88	–	34	8
	Phylum Sipuncula	–	–	–	–	–	–	–	32	–	27
	Phylum Echiura	–	–	–	–	–	–	–	43	–	7
	Phylum Annelida	13	178	28	105	336	111	128	570	108	332
	Phylum Onychophora	–	1	–	–	–	–	–	–	–	–
	Phylum Arthropoda	2415	26,480	1966	5356	13,750	11,026	10,905	2023	14,956	4838
	Subphylum Chelicerata	82	1075	266	685	1413	926	837	30	773	168
	Class Arachnida	82	1075	266	685	1413	926	837	–	773	159
	Class Merostomata	–	–	–	–	–	–	–	2	–	–
	Class Pycnogonidia	–	–	–	–	–	–	–	28	–	9
	Subphylum Crustacea	22	277	111	226	244	294	247	1987	190	1079

(continued)

Table 18.3 (continued)

Kingdom	Phylum	Trans-Himalaya	Indian Himalaya	Desert	Semi-Arid	Western Ghats	Deccan Peninsula	Gangetic Plains	Coasts	North East	Island
	Subphylum Hexapoda	2311	25,021	1580	4419	11,755	9806	9821	6	13,942	3572
	Class Collembola	30	147	16	15	121	60	49	–	59	18
	Class Diplura	–	2	–	–	–	–	–	–	–	–
	Class Protura	–	–	–	–	20	–	1	–	–	–
	Class Insecta	2281	24,932	1564	4404	11,615	9746	9772	6	13,883	3554
	Subphylum Myriapoda	–	107	–	26	157	80	41	–	51	19
	Class Chilopoda	–	51	8	21	33	20	22	–	22	17
	Class Diplopoda	–	52	1	5	124	60	19	–	27	2
	Class Symphyla	–	4	–	–	–		–	–	2	–
	Phylum Phoronida	–	–	–	–	–	–	–	2	–	2
	Phylum Bryozoa (Ectoprota)	–	4	9	11	–	8	6	245	9	53
	Phylum Entoprocta	–	–	–	–	–	–	–	3	–	–
	Phylum Brachiopoda	–	–	–	–	–	–	–	8	–	2
	Phylum Chaetognatha	–	–	–	–	–	–	–	29	–	20
	Phylum Tardigrada	–	23	–	–	–	–		4	11	4
	Phylum Mollusca	76	422	36	93	387	97	143	2690	402	1351
	Phylum Nemertea	–	–	–	–	–	–	–	8	1	2
	Phylum Echinodermata	–	–	–	–	–	–	–	440	–	478
	Phylum Hemichordata	–	–	–	–	–	–	–	13	–	1
	Phylum Chordata	573	1816	–	1087	1674	1386	1241	2413	1695	2137

	Subphylum Cephalochordata	–	–	–	–	–	–	-	9	–	–
	Subphylum Urochordata	–	–	–	–	–	–	-	219	–	76
	Subphylum Vertebrata (Craniata)	573	1816	770	1087	1674	1386	1241	2185	1695	2061
	Pisces	100	316	121	177	397	287	232	1905	436	1576
	Amphibia	8	80	11	30	253	88	38	–	117	16
	Reptilia	16	200	75	109	270	112	136	31	165	69
	Aves	349	940	494	657	617	765	711	224	800	344
	Mammalia	100	280	69	114	137	134	124	25	177	56
	Total (Animalia)	**3307**	**30,243**	**3277**	**7522**	**16,724**	**13,399**	**14,108**	**11,180**	**18,284**	**10,733**
Grand Total (Protista + Animalia)		**3324**	**30,615**	**3346**	**7742**	**17,099**	**13,911**	**14,630**	**11,882**	**18,527**	**11,009**

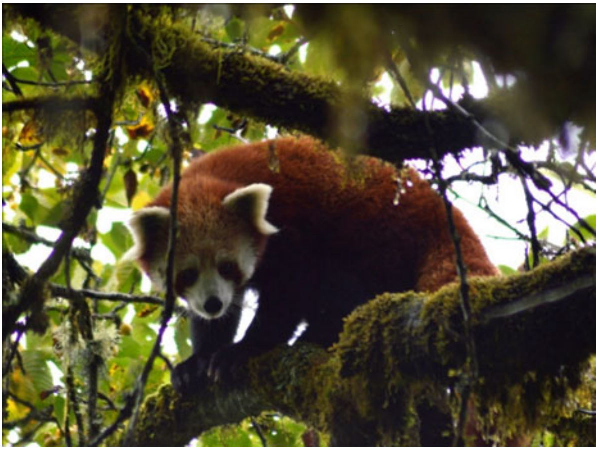
The total number of species in columns in the table comprises the total number of species in different phyla

Source: Trans-Himalaya: Chandra et al. (2019b); Himalaya: Chandra et al. (2018a, 2020c); Desert: Chandra et al. (2021b); Semi-Arid: Chandra et al. (2021c); Western Ghats: Chandra et al. (2020b); Gangetic Plains: (Chandra et al. 2022); Deccan Peninsula: ZSI; Coast: Chandra et al. (2020a); Northeast: Chandra et al. (2021a); Islands: Chandra and Raghunathan (2018)

18.5 Himalaya

The Himalayas spread over 2400 km in length across India, Nepal, Bhutan, China, and Pakistan and holds the most climaxed peaks and bulkiest glaciers on Earth's face. There are more than 30 peaks with heights of 7620 m or more, and Mount Everest (8848 m), K2 (8611 m), and the Kangchenjunga (8586 m) among them are the world's highest mountains. The Himalayan mountains in India extend from Jammu and Kashmir in the West, reaching Arunachal Pradesh in the East, traversing six states: Jammu and Kashmir, Himachal Pradesh, Uttarakhand, Sikkim, West Bengal (Darjeeling and Kalimpong), and Arunachal Pradesh. The Himalaya Zone enclaves ~6.4% (2,10,662 sq. km) of the country's total geographical area (Rodgers et al. 2002). Four biotic provinces fall under this biogeographic zone: Northwest Himalaya (2A), West Himalaya (2B), Central Himalaya (2C), and East Himalaya (2D). Politically, the parts of Himachal Pradesh and Jammu and Kashmir are classified under Northwest Himalaya, Uttarakhand and some areas of Himachal under West Himalaya, hills of Darjeeling (West Bengal) and Sikkim under Central Himalaya, and the state of Arunachal Pradesh under East Himalaya.

Ursus thibetanus (Cuvier 1823), Asian black bear (Photo Credit: ZSI)



Ailurus fulgens (Cuvier 1825), red panda (Photo Credit: ZSI)

The Himalayan biogeographic zone is diverse in species diversity, representing 30,615 faunal species, known from this zone (Table 18.3), over 30% of India's faunal diversity. Over 28,427 species are invertebrates, 1816 species are vertebrates, and 372 are protozoans. Arthropoda, with about 26,480 species/subspecies known from the Himalayas, represents approximately 86.4% of this region's total diversity (Table 18.3). As far as vertebrate diversity is concerned, 316 species of fishes, 80 species of amphibians, 200 species of reptiles, 938 species of birds, and 280 species of mammals account for about 27% of the total vertebrate diversity of the country (Table 18.3). A total of 133 vertebrate species are threatened under IUCN Red List 2021: 14 species are critically endangered, 35 endangered, and 84 vulnerable. Central Himalaya has the highest faunal diversity with 14,373 species, followed by West Himalaya (12,127), Northwest Himalaya (8849), and East Himalaya (5689) (Table 18.4).

18.6 Desert

The Desert is described as areas having "low rainfall and humidity, extreme air temperatures, strong wind, lower organic content and higher minerals in the soil, infrequent river systems, severe erosion by water and wind, and inadequate nominal dendritic drainage." Africa is home to 36.7%, Asia 31.7%, North America 12%, Australia 10.8%, and South America 8.8% of the global area under arid region (Meigs 1957). The Indian Desert Biogeographic Zone spreads over an area of 2,15,757 sq. km in Rajasthan and Gujarat, comprising 6.56% of the total landmass of the country, further divided into two biotic provinces: Thar-Desert (3A) and Kachchh (3B). Contradictory to the prevailing view, the Indian Desert is reasonably diverse and unique in animal life. Thar's biodiversity may not be comparatively

Table 18.4 Faunal diversity in different Himalayan, Northeastern, and Desert ecosystems of India

Phylum/class	Northwest Himalaya	West Himalaya	Central Himalaya	East Himalaya	Brahmaputra Valley	Northeast Hills	Thar Desert	Kachchh
Phylum Protozoa	141	99	168	67	67	240	69	–
Phylum Porifera	1	5	–	–	3	3	6	–
Phylum Cnidaria	1	1	1	1	1	4	2	–
Phylum Platyhelminthes	126	97	4	5	26	212	92	–
Phylum Rotifera	173	115	167	172	207	283	46	–
Phylum Gastrotricha	–	–	–	–	3	5	–	–
Phylum Kinorhyncha	–	–	–	–	–	–	–	–
Phylum Nematoda	383	308	94	36	68	475	313	12
Phylum Acanthocephala	27	1	9	1	3	33	7	–
Phylum Annelida	79	93	84	42	38	95	27	1
Phylum Arthropoda	7097	10,440	12,709	4062	7079	11,501	1898	274
Class Arachnida	356	326	440	179	262	644	229	45
Crustacea	173	47	108	37	156	143	111	–
Class Collembola	68	31	55	21	18	55	16	–
Class Diplura	–	1	1	–	–	–	–	–
Class Protura	–	–	–	–	–	–	–	–
Class Insecta	6445	10,002	12,053	3819	6617	10,621	1533	229
Class Chilopoda	46	29	11	4	8	21	8	–
Class Diplopoda	8	4	37	–	18	15	1	–
Class Symphyla	1	–	4	2	–	2	–	–
Phylum Bryozoa (Ectoprota)	1	–	4	2	5	5	9	–
Phylum Tardigrada	–	23	–	–	–	11	–	–
Phylum Mollusca	65	49	140	210	135	345	28	26
Phylum Nemertea	–	–	–	–	1	–	–	–
Phylum Chordata	755	896	993	1091	–	–	658	581

Pisces	56	110	98	231	208	395	116	33
Amphibia	18	23	43	59	47	118	9	8
Reptilia	46	84	102	108	111	148	64	49
Aves	524	564	611	539	699	798	239	494
Mammalia	111	115	139	154	131	167	67	56
Total (Animalia)	**8708**	**12,028**	**14,205**	**5622**	**8765**	**14,598**	**3086**	**894**
Grand Total (Protista + Animalia)	**8849**	**12,127**	**14,373**	**5689**	**8832**	**14,838**	**3155**	**894**

The total number of species in columns in the table comprises the total number of species in different phyla

Source: Northwest, West, Central, and East Himalayas: Chandra et al. (2018a); Thar Desert and Kachch: Chandra et al. (2021b); Brahmaputra Valley and Northeast Hills: Chandra et al. (2021a)

Kchchch fauna includes only terrestrial species wealthy, but it is unique because of the following two main reasons. First, the Thar is the extension of the Sahara Desert through the Persian and Arabian deserts and is located at the convergence of Palaearctic and Oriental regions. Hence, it has the admixture of Palaearctic, Oriental, and Saharan elements in the biodiversity. Second, both floral and faunal components constitute an invaluable stock of rare and resistant germplasm.

Literature records on faunal diversity suggest that all the major invertebrate and vertebrate groups and even microscopic protozoans are found in the Indian desert region. However, most of the animals except birds and a few diurnal mammals are not easily noticeable. The animal life in the deserts survives by hiding in the burrows, long tunnels, under stones, plant leaves and roots, ponds, puddles, and larger reservoirs and lakes. Most of the animals remain active during the night as they go inside their burrows during day time. The diversity and distribution of vertebrates have been extensively studied through faunal explorations and observations, whereas the invertebrates remain unexplored to date. The Rann of Kachchh exhibits spectacular biodiversity because of its evolutionary history, geographical location, and salt desert's ecological uniqueness.

Ardeotis nigriceps (Vigors 1831) (great Indian bustard) (Photo Credit: ZSI)

A total of 3346 species of different faunal groups, belonging to 1893 genera and 644 families, have been recorded from Indian Desert Zone (Table 18.3). Protozoans comprise 69 species, invertebrates 2507 species, and vertebrates 770 species. The faunal diversity of the Indian Desert Zone represents 3.3% of the total diversity of the country. Compared with the country's terrestrial fauna, Indian Desert Zone represents approximately 4.0% of the country's land diversity. Out of the total desert fauna, 3155 species are reported from Thar-Desert, and 894 species are reported from Kachchh (Table 18.4). Desert is home to six birds, which are critically endangered: *Leucogeranus leucogeranus* (Pallas), Siberian crane; *Ardeotis nigriceps* (Vigors), great Indian bustard; *Vanellus gregarius* (Pallas), sociable lapwing; *Gyps* *bengalensis* (Gmelin), white-rumped vulture; *Gyps indicus* (Scopoli), Indian vulture; and *Sarcogyps calvus* (Scopoli), red-headed vulture.

18.7 Semi-Arid

The Semi-Arid Biogeographic Zone spreads over 5,45,850 sq. km, comprising 16.60% of the country's total landmass. Semi-Arid Zone is further divided into two biotic provinces: Punjab Plains (4A) and Gujarat Rajputana (4B). Gujarat Rajputana covers more than 77.2% of Semi-Arid's total area zone, and the rest of the 22.8% area comes under Punjab Plains. Punjab, Haryana, Chandigarh, Delhi, Jammu and Samba districts in Jammu and Kashmir, and Agra and Mathura districts in Uttar Pradesh form the Punjab Plains. Gujarat Rajputana includes the Eastern Rajasthan, Western Madhya Pradesh, and Gujarat. This zone with a 400–1000-mm rainfall is a transition zone between the Desert and Western Ghats' dense forests. As per Roy et al. (2012), this zone has relatively less area under natural vegetation and over 46.02% of the overall area utilized for agriculture. The dry deciduous forests in this zone constitute 5.58% of the total geographic area, dry deciduous scrub 2.46%, and scrub savanna 2.81%.

Altogether 7742 species of different faunal groups, belonging to 3693 genera and 836 families in 12 significant phyla, have been reported from Semi-Arid Zone (Table 18.3). The faunal diversity of this zone represents nearly 7.6% of India's overall faunal diversity. Protozoans comprise 220 species, invertebrates 6435 species, and vertebrates 1087 species. Semi-Arid diversity accounts for about 17.3% of species of overall Indian vertebrate diversity, of which Pisces recorded with 177 species, Amphibia 30 species, Reptilia 109 species, Aves 657 species, and Mammalia 114 species.

18.8 Western Ghats

The Western Ghats mountain chains constitute the significant share of the Western Ghats-Sri Lanka biodiversity hotspot, traversing Gujarat, Maharashtra, Goa, Karnataka, Tamil Nadu, and Kerala. The range of mountains spread parallel to the west coast of peninsular India and is traditionally known as Sahyadri (Radhakrishna 2001). Compared to the other hotspots, it has the highest human population density (more than 300 persons/sq. km), which poses several conservation challenges. The Western Ghats is well known for its rich biodiversity and has a high proportion of endemic species.

The mountains in this zone support 17,099 faunal species, contributing 16.74% of Indian fauna (Table 18.3). Protozoans are represented by 375 species, invertebrates 15,050 species, and vertebrates 1674 species (Table 18.3). Arthropods are the dominant group in the region with 13,570 species. Western Ghats' fauna has a high degree of endemism, and 24.53% of species of animals are exclusive to this region. There are over 617 species of birds, 397 species of fishes, 270 species of reptiles, 253 species of amphibians, and 137 species of mammals known from this zone. It is pertinent to note here that over 43.61% of vertebrates are endemic to the Western Ghats. Nilgiri Langur, *Semnopithecus johnii* (Fischer), Lion-tailed Macaque, *Macaca sielnus* (Linnaeus), and Grey Langur, *Semnopithecus hypoleucos* Blyth are the endemic primates, known from a few populations in evergreen patches of southern Western Ghats. Nilgiri Tahr, an endangered ungulate, is distributed to few localities in higher elevations between Nilgiris and Ashambu Hills in the south Western Ghats. The Malabar Civet, a critically endangered species, is considered one of the world's rarest mammals found only in the southern Western Ghats.

18.9 Deccan Peninsula

The Deccan Peninsula Biogeographic Zone in the south of the Narmada river is the most widespread in India, covering over 43% of its total landmass (Cherian 2001). The Peninsular Plateau is highest in the south and west and slopes eastwards, and the western edge of the plateau forms the escarpment of the Western Ghats. The eastern boundary is much broken and is known as the Eastern Ghats. The Deccan's average altitude is about 2000 ft. (600 m), sloping generally eastward. This large zone is relatively homogeneous and is distinct from the neighboring zones: the Western Ghats, semi-arid, and Gangetic plain zones. There are five major recognizable subdivisions in this zone: (1) Deccan plateau south, (2) Deccan plateau north, (3) the Eastern Highlands, (4) Chota Nagpur, and (5) Central Highlands. The zone supports over 13,911 faunal species, contributing 13.6% of Indian fauna (Table 18.3). Protozoans are represented by 512 species, invertebrates 12,013 species, and vertebrates 1386 species. Arthropods are the dominant group in the region with 11,026 species. There are over 765 species of birds, 287 species of fishes, 112 species of reptiles, 88 species of amphibians, and 134 species of mammals known from this zone.

18.10 Gangetic Plains

Gangetic Plain Zone is one of the most fertile areas globally and supports one of the densest populations. In this zone, almost all the forests have been converted into croplands. The Gangetic plains are flat alluvial regions lying north and south of the Ganges and encompassing various tributaries. The Vindhyan escarpment and the northern and eastern outliers of the Chhotanagpur plateau form the southern boundary of this zone, while the Himalayas are toward the north. There is a clear west–east moisture gradient, with less than 500-mm rainfall in the western part of the plain, whereas the eastern part receives more than 5000 mm of precipitation.

Biogeographically, the Gangetic can be divided into two provinces: Upper Gangetic plain and Lower Gangetic plain. A total of 14,630 faunal species of different phyla are reported from Gangetic Plain Zone (Table 18.3). Animals include 14,108 species and protozoa 522 species. Phylum Arthropoda is with maximum diversity of 10,905 species. The region is also home to 232 species of fishes, 38 species of amphibians, 136 species of reptiles, 711 species of birds, and 124 species of mammals.

18.11 Coasts

India has over 7516.6-km-long coastline, spread across West Bengal, Odisha, Andhra Pradesh, Tamil Nadu, Kerala, Karnataka, Goa, Maharashtra, Gujarat Lakshadweep, and Puducherry. Indian coasts share a stretch of 2.02 million sq. km of Exclusive Economic Zone (EEZ), 3,72,424 sq. km of continental shelf area, and 1,93,834 sq. km of territorial waters in the Indian geospatial boundary (Chandra et al. 2020e). The coastal regions are enriched with a wide range of ecosystems such as mangroves, creeks, deltaic plains, saline wetlands, tidal flats, estuaries, gulf waters, coral reefs, soft sediment oceanic floor, and mesophotic reefs (Raghunathan et al. 2016). The Eastern Coast extends 2545.1 km from West Bengal to Kanyakumari (Tamil Nadu). The Western Coasts (including 132 km. of Lakshadweep) extend 3009.5 km from Gujarat and Kerala. The coastal region in Odisha is known as the Utkal coast, while some parts of the Andhra Pradesh coastal area and Tamil Nadu coastal regions are known as the Coromandel coast. India's coastal biogeographic zone supports over 11,883 faunal species in 56 major groups (Table 18.3). Over 55% of the costal faunal diversity is represented by three groups; mollusks, crustaceans, and fishes. Mollusk represents the most diverse group in this ecosystem with over 2379 species, representing 51.6% of the country's overall molluskan diversity (Table 18.3). The crustacean diversity of the coasts includes 1987 species, representing 51.1% of India's overall crustacean fauna. Over 56% of Indian fish diversity is reported to occur on the coasts. With regard to diversity in coastal states, Tamil Nadu is rich with over 5344 species followed by Lakshadweep (3008), Andhra Pradesh (2257), Kerala (2221), Maharashtra (2033), Odisha (2018), West Bengal (1540), Gujarat (1714), Karnataka (1296), Goa (632), and Puducherry (373) (Chandra et al. 2020a).

18.12 Northeast

The Northeast Zone comprises Assam, Meghalaya, Nagaland, Manipur, Mizoram, and Tripura and is divided into two biotic provinces: Brahmaputra Valley (9A) and Northeastern Hills (9B). The region is the transition zone between Indo-Malayan and Indo-Chinese geographical regions and a meeting point of the Himalayan Mountains and Peninsular India (Mani 1974). The zone's total landmass is 1,71,341 sq. km, sharing 5.21% of the total Indian landmass. Northeast India (except Brahmaputra Valley) and the Andaman group of Islands are a part of the Indo Burma biodiversity hotspot (Myers 1988; Myers et al. 2000). The Northeast Zone is adorned with diverse ecosystems like forests, grasslands, and wetlands, including marshes, swamps, ponds and lakes, streams, and rivers, each of which comprises an enormous variety of habitats (Alfred et al. 2001). The altitudinal variations and climate variability determine the pattern of vegetation in the region. As per the Indian State of Forest Report-2019, the Northeast Zone includes nearly 58.66% area under forests, out of the six states' total combined area. Except for Assam, most of the states of NE have 70–85% of their territory occupied by forests, with the state of Mizoram having the highest percentage of forest cover. Northeast Zone altogether harbors over 18,527 species in 15 phyla of both Protozoa (243) and Animalia (18,284), representing about 18% of the total Indian fauna (Table 18.3). Phylum Arthropods with 14,956 species represent 80.7% of the overall faunal diversity of the Northeast Zone. The region is also home to 436 species of fishes, 117 species of amphibians, 165 species of reptiles, 800 species of birds, and 177 species of mammals.

Regarding faunal diversity in its biotic provinces, Northeast Hills includes 14,838 species and Brahmaputra Valley 8832 species. Meghalaya has over 9853 species, Assam 9607 species, Manipur 5036 species, Nagaland 3869 species, Tripura 3605 species, and Mizoram 3020 species (Chandra et al. 2021a). The zone also has 153 threatened species distributed, representing about 22.35% of total Indian threatened fauna.

Rhinoceros unicornis (Linnaeus 1758) (greater one-horned rhinoceros) (Photo Credit: ZSI)

The Himalayan Newt (*Tylototriton verrucosus* Anderson) is the only Salamander species known from India, occurring in Manipur, Khasi Hills, and Nagaland (Mathew and Sen 2010). Northeast is a "turtle hotspot" and home to 21 out of 29 species of freshwater turtles and tortoises found in India. Among birds, the greater adjutant *Leptoptilos dubius* (Gmelin) is critically endangered, with most of the world's population now located in Assam. The black-necked stork *Ephippiorhynchus asiaticus* (Latham), the lesser adjutant *Leptotilos javanicus* (Horsfield), and the pale-capped pigeon *Columba punicea* Blyth are significant globally threatened birds found in the region. The Bengal florican *Houbaropsis bengalensis* (Gmelin), a critically endangered and one of the rarest bustards, has the most significant global population in the Manas National Park. Among six big cats recorded from India, *Panthera tigris* (Linnaeus) (Tiger), *P. pardus* (Linnaeus) (leopard), and *Neofelis nebulosa* (Griffith) (clouded leopard) have been reported from the region. The brow-antlered deer *Rucervus eldii* (Mc Clelland), locally known as the Sangai, is endemic to Manipur and is one of the rarest and the most localized subspecies of deer in the world. The pygmy hog *Sus scrofa* Linnaeus is the smallest and the most unique wild species, with a few isolated wild populations surviving in Northeast Zone.

18.13 Islands (Andaman and Nicobar Islands)

Islands are one of the world's vital ecosystems that support a broad spectrum of biodiversity, geographically isolated from the main landmass. Oceanic and atmospheric attributes and water influence uniqueness in its characterization (Granger 1993). The island ecosystem's biodiversity is invariably impacted by climatic elements, geospatial properties of the habitat, and anthropogenic practices (Balzan et al. 2016). Islands cover 5% of the earth's surface and are home to 10% of the human population (IUCN 2021). They also support more than 15% of global terrestrial biodiversity, with many species restricted (endemic) to a single island or archipelago (IUCN 2021). The Andaman and Nicobar Islands (A & N) comprise an arcuate chain of more than 572 islands, islets, and rocks, with 8249 sq. km between the Bay of Bengal and the Andaman Sea with a 1962 km coastline (Venkataraman et al. 2003). They are also commonly known as the Bay Islands. They lie from 6° to 14° North latitudes and from 92° to 94° East longitudes. The islands have an undulating terrain and intervening valley mostly covered with dense tropical rain forests. Andaman group of islands have a landmass cover of 6408 sq. km (550 islands) and Nicobar group of Islands with 1841 sq. km having 22 islands (Venkataraman et al. 2003), and the ten-degree channel that separates both of them significantly contributes to the zoogeographical distribution of faunal component. Andaman and Nicobar Islands harbors over 11,009 faunal species in 24 phyla (Table 18.3). Animals include 10,733 species and protozoa 276 species (Table 18.3). With only 0.3% of the county's landmass, A & N contributes 10.88% of the Indian faunal diversity. Rao et al. (2017) reported over 1032 species, endemic to this island, of which 816 are terrestrial and 216 marine fauna. Among vertebrates, a maximum of 50% of endemism is found in reptiles by amphibians 45%, mammals 41%, and birds 35%. Regarding terrestrial invertebrates, the highest 66% endemism is shown by mollusks, followed by insects 24% and annelids 23% (Rao et al. 2017).

18.14 Ecosystems

India is blessed with extremely variable ecosystems such as natural forests, grasslands, high-altitude mountains, wetlands, mangroves, coral, deserts, freshwater, and marine ecosystems. Out of the overall Indian fauna, 20,444 species are exclusively found in the marine ecosystem, and 10,168 species are in freshwater (Table 18.5). Overall, 30% of India's faunal diversity is dependent on the aquatic (both marine and freshwater) ecosystem. Soil, mangrove, and estuarine ecosystems have 22,586 species, 4826 species, and 3392 species, respectively (Table 18.5). The diversity of natural terrestrial ecosystems, freshwater, marine, estuarine, mangrove soil, and agroecosystems are discussed briefly below.

18.14.1 Terrestrial Fauna

Due to its varied physical features and geographical location, India experiences almost all kinds of climate, from tropical to alpine and from Desert to humid. Based on temperature, India's landmass can be broadly classified into four zones: tropical, subtropical, temperate, and alpine (or arctic). Out of 1,03,345 faunal species known from India, 85,474 species are associated with the terrestrial ecosystems (including freshwater) such as forests, mangroves, deserts, wetlands, Northwest Himalaya, West Himalaya, Central Himalaya, East Himalaya, and Trans-Himalaya (Tables 18.5 and 18.6).

Table 18.5 Faunal diversity in ecosystems of India with their respective number of faunal species

Ecosystem	Number of faunal species	Percentage of Indian fauna
Terrestrial	85,198	82.7
Freshwater	10,168	9.5
Marine	20,444	19.8
Estuarine	3392	3.3
Mangrove	4826	4.7
Soil	22,586	21.9
Agroecosystem	5820	5.6

Table 18.6 Faunal diversity in different ecosystems of India

Kingdom	Phylum	Freshwater	Marine	Estuarine	Mangrove	Soil	Agroecosystem	Terrestrial
Protista	Phylum Protozoa	291	2577	188	349	182	65	968
Animalia	Phylum Mesozoa	–	10	–	–	–	–	–
	Phylum Porifera	31	518	4	5	–	–	31
	Phylum Cnidaria	9	1444	92	73	–	–	9
	Phylum Ctenophora	–	19	5	4	–	–	–
	Phylum Platyhelminthes	163	878	–	1	–	–	911
	Phylum Rotifera	467	47	38	53	419	–	420
	Phylum Gastrotricha	24	100	–	1	–	–	63
	Phylum Kinorhyncha	–	10	–	1	–	–	–
	Phylum Nematoda	422	473	30	125	2949	1535	2476
	Phylum Acanthocephala	140	229	1	–	–	–	77
	Phylum Sipuncula	–	41	1	1	–	–	–
	Phylum Echiura	–	47	–	–	–	–	–
	Phylum Annelida	167	590	269	269	590	115	492
	Phylum Onychophora	–	–	–	–	–	–	1
	Phylum Arthropoda	6607	2856	1006	2390	17,035	3509	74,667
	Subphylum Chelicerata	259	38	83	311	2856	319	6082
	Class Arachnida	259	–	81	309	2856	319	6082
	Class Merostomata	–	2	2	2	–	–	–
	Class Pycnogonidia	–	36	–	–	–	–	–
	Subphylum Crustacea	822	2808	655	624	83	60	1101
	Subphylum Hexapoda	5526	10	265	1455	13,707	3130	67,101
	Class Collembola	–	–	–	33	345	39	345
	Class Diplura	–	–	–	–	18	–	18
	Class Protura	–	–	–	–	20	–	20
	Class Insecta	5526	10	265	1422	13,323	3091	66,718
	Subphylum Myriapoda	–	–	3	3	389	–	383

(continued)

Table 18.6 (continued)

Kingdom	Phylum	Freshwater	Marine	Estuarine	Mangrove	Soil	Agroecosystem	Terrestrial
	Class Chilopoda	–	–	–	3	90	–	101
	Class Diplopoda	–	–	3	–	289	–	272
	Class Symphyla	–		–	–	10	–	10
	Phylum Phoronida	–	3	–	–	–	–	–
	Phylum Bryozoa (Ectoprota)	22	272	4	2	–	–	65
	Phylum Entoprocta	1	4	–	1	–	–	6
	Phylum Brachiopoda	–	8	3	2	–	–	–
	Phylum Chaetognatha	–	44	14	15	–	–	–
	Phylum Tardigrada	10	8	–	–	41	–	43
	Phylum Mollusca	217	3789	426	173	1130	–	1438
	Phylum Nemertea	–	6	–	1	–	–	–
	Phylum Echinodermata	–	784	28	8	–	–	–
	Phylum Hemichordata	–	14	1	1	–	–	–
	Phylum Chordata	1597	3047	–	1545	240	596	3807
	Subphylum Cephalochordata	–	6	–	–	–	–	–
	Subphylum Urochordata	–	531	6	6	–	–	–
	Subphylum vertebrata (Craniata)	–	2510	–	1339	240	596	3807
	Pisces	1027	2412	764	659	–	218	1027
	Amphibia	275	–	39	14	124	43	433
	Reptilia	46	32	71	57		64	638
	Aves	243	33	347	523	–	244	1312
	Mammalia	6	33	55	86	116	27	397
	Total (Animalia)	**9887**	**17,867**	**3204**	**4477**	**22,404**	**5755**	**84,506**
Grand Total (Protista + Animalia)		**10,168**	**20,444**	**3392**	**4826**	**22,586**	**5820**	**85,474**

The total number of species in columns in the table comprises the total number of species in different phyla

Source: Freshwater: Chandra et al. (2017a); Marine: Chandra et al. (2016, 2017b); Estuarine: Chandra et al. (2018b); Mangrove: Chandra et al. (2019a) and Mishra (2020); Soil: Chandra et al. (2019c, 2020d); Agroecosystem: Chandra et al. (2021d)

18.14.2 Freshwater

The freshwater ecosystems of India include all types of inland wetlands: lakes, rivers, ponds, streams, groundwater, springs, cave waters, floodplains, and bogs, marshes, and swamps. India with 2.4% of the global landmass has 4% of the world's freshwater resources (Ministry of Water Resources, Govt. of India). As per estimates by the National Wetland Inventory and Assessment by MoEFCC, Govt. of India, India has over 10.56 million hectares of inland wetlands in India, comprising 6.62 million hectares of natural 3.94 million hectares of artificial wetlands. With over 115 wetlands identified under the National Wetland Conservation Programme (NWCP), the total area of Indian wetlands is only 0.03% of the geographical extent of the country. Forty-two wetlands have been declared as Ramsar Wetland Sites. Freshwater ecosystems support hundreds of freshwater species of different groups, invertebrates like annelids (polychaetes, earthworms, leeches, etc.), arthropods (insects and crustaceans), fishes, amphibians, and mollusks (snails and mussels).

In India, freshwater ecosystems represent approximately 9.9% of the total number of faunal species. Out of 10,168 freshwater faunal species known from India, phylum Arthropoda alone represents 6607 species, 61.4% of the overall fauna (Tables 18.5, 18.6). Among arthropods, insects are the dominant group, with 5526 species in Diptera (1588 species), Coleoptera (776), Odonata (496), Hemiptera (325), Plecoptera (146), Ephemeroptera (146), Trichoptera (1261), Lepidoptera (80), and Hymenoptera (10). Crustaceans are the other major group, followed by Arachnids (259: mites 253 and spiders 6). The other invertebrate groups in freshwater ecosystems in India are Nematoda (422 species), Rotifera (419), Mollusca (217), Annelida (167), Platyhelminthes (Turbellaria 47 + Cestoda 116), Acanthocephala (140), Porifera (31), Gastrotricha (24), Bryozoa (22), Tardigrada (10), Cnidaria (9), and Entoprocta (1). There are over 1027 species of fishes, 275 species of amphibians, 243 species of birds, 46 species of reptiles, and 6 species of mammals, distributed in the freshwater ecosystem. Phylum Protozoa (291 species) has a share of 3.0% of the total freshwater fauna.

18.14.3 Marine

The marine habitats are a combination of ecosystems such as shallow coral reefs, mesophotic reef, soft sediment at the ocean floor, coastal estuaries, saline wetlands, mangroves, gulf waters, creeks, tidal flats, and deltaic plains. Despite the studies on India's marine faunal communities, documented from the shallow regions of the ocean floor, a lot remains unexplored in the deep sea. Over 20,444 faunal species are reported from marine coastal areas around India, contributing 7.01% of the global marine fauna (Tables 18.5 and 18.6). Protozoan diversity in the Indian sea includes a total of 2577 species under six phyla (Table 18.6). Among Cnidarians, the maximum of 1117 species belong to Anthozoa, 178 species to Hydrozoa, 30 species to

Scyphozoa, 5 species to Cubozoa, and one species to Staurozoa. Crustaceans (2808 species), mollusks (2690 species), and fishes (2412 species) are the most diverse group of animals. India harbors 784 species of echinoderms, 32 species of reptiles, 33 species of birds, and 33 species of mammals. Of 32 species of marine reptiles reported from Indian seas, 26 species are sea snakes, 5 species of sea turtles, and the saltwater crocodile. Five sea turtle species are loggerhead sea turtle, green sea turtle, hawksbill sea turtle, olive ridley sea turtle, the leatherback sea turtle from Indian coastlines and Andaman and Nicobar Island, all of them protected in the Wildlife Protection Act, 1972 under Schedule I. Hawksbill sea turtle is critically endangered, green sea turtle endangered, loggerhead sea, olive ridley sea turtle, and leatherback sea turtle vulnerable as per IUCN Red List of threatened species. Exclusively 33 species of pelagic birds are reported from Indian marine and coastal habitats. The Indian seas support 33 species of marine mammal in the families Delphinidae, Physeteridae, Kogiidae, Ziphiidae, Phocoenidae, and Platanistidae (Kumaran 2002; Vivekanandan and Jeyabaskaran 2012).

18.14.4 Estuaries

Estuaries are transition zone, separating the marine and terrestrial ecosystems and are productive ecosystems worldwide. Most of India's significant estuaries are situated on the east coast, joining with the Bay of Bengal. The estuarine ecosystem is a habitat for ecologically, commercially, recreationally, and culturally valuable floral and faunal communities. The estuaries are often called nurseries of the sea as many fish and wildlife species depend on estuaries for sheltered waters and protected spawning places. Migratory and coastal birds, fishes, amphibians, insects, and other wildlife depend on estuaries to live, forage, nest, and reproduce. The oysters make estuaries their permanent home through adaptations to osmotic stress; others, like horseshoe crabs, use them to complete only part of their life cycle. The estuarine ecosystem in India harbors over 3392 faunal species, including 188 protozoans, 2420 invertebrates, and 764 vertebrates (Tables 18.5 and 18.6). There are over 764 species of fishes, 39 species of amphibians, 71 species of reptiles, 347 species of birds, and 55 species of mammals.

18.14.5 Mangroves

India's mangrove area covers 4921 sq. km, with 57% formation on the east coast, 30% on the west coast, and 13% in the Andaman and Nicobar Islands (Kathiresan 2018). Out of 130 mangrove species reported from India, 44 are true mangroves, and 86 are mangrove associates (Kathiresan et al. 2013). Over 4826 faunal species in

21 phyla were documented from mangrove habitats in India, representing 4.76% of Indian fauna (Tables 18.5). Of them, 349 species are protozoans, 2932 species are invertebrates, and 1339 species vertebrates (Table 18.6). The arthropods remain the dominant group with 2390 species. Most of the faunal groups are not reported or under-reported in mangroves of the western coast of India.

18.14.6 Soil

Soil is a fundamental stratum that supports varied faunal and floral communities and manages the whole ecosystem. The organisms associated with the soil ecosystem can be classified into four major groups based on their body width: microfauna (less than 0.1 mm), mesofauna (0.1–2 mm), macrofauna (2–20 mm), and megafauna (bigger than 20 mm) (Orgiazzi et al. 2016). Protozoans, tardigrades, rotifers, and nematodes are soil microfauna, whereas mites, pseudoscorpions, and apterygote insects are mesofaunal soil communities. Earthworms, spiders, scorpions, isopods, ants, ground-dwelling bees and wasps, termites, earwigs, soil-dwelling beetles, web spinners, grasshoppers, locusts, crickets, cockroaches, millipedes, centipedes, pauropods, symphylans, snails, and slugs form the macrofaunal soil communities. Small mammals, adult salamanders, caecilians, snakes, and lizards are soil megafauna. Over 22% of India's faunal diversity (22,586 species) directly and indirectly depend on soil ecosystems, including 17,035 species of arthropods, 2945 species of nematodes, 590 species of annelids, 1130 species of mollusks, 429 species of rotifers, 240 species of vertebrates, and 182 species of protozoans (Table 18.6). Regarding the response of belowground fauna to climate change, very little has been studied so far. Climate change, land-use patterns, intensive human exploitation, soil erosion, industrial and radioactivity pollution, and genetically modified crops pose a significant threat to soil faunal communities, compared to other terrestrial habitats (Anderson 1975; Usher et al. 1979; Giller 1996; Ruiz et al. 2008).

18.14.7 Agroecosystems

An agroecosystem as a subset of a conventional ecosystem involves the human activity of agriculture and associated areas. India has 15 different agro-climatic zones that determine and influence the nature of agrobiodiversity. Agrofaunal diversity essentially includes livestock breeds, fishes, non-domesticated animals, soil microbiota, pollinators, and other insects such as bees, butterflies, earthworms, greenflies, and non-harvested species in the broader environment that support food production ecosystems. Over half of the agroecosystem diversity is represented by insects (3091 species) and collembolans (30 species). Nematodes (1535 species) are the second largest group, followed by birds (244 species), fishes (218 species), annelids (115 species), protozoans (65 species), reptiles (64 species), amphibians (43 species), and mammals (27 species) (Table 18.6).

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Part V
Challenges and Reasons of Biodiversity Loss

Chapter 19
Challenges on Account of Invasive Alien Terrestrial Plants

Amarpreet Kaur, Daizy R. Batish, and Ravinder Kumar Kohli

19.1 Biological Invasions: Concept, History, and Current Perspective

Human-mediated intentional or accidental migration of exotic species beyond their native geographical range leads to a well-known phenomenon, *biological invasion*. Expansion of international trade, transport, and tourism led to the breakdown of biogeographic barriers and enhanced the cross-border movement of non-indigenous species (Meyerson and Mooney 2007; Hulme 2009; Capinha et al. 2015; Bertelsmeier et al. 2017). A small proportion of these migrated species, competent enough to endure the biotic and abiotic challenges presented by the novel habitat and capable of causing apparent ecological and economic impacts are defined as *invasive species* (Richardson et al. 2000; Canning-Clode 2015; Kaur et al. 2019; Shackleton et al. 2019). Being a second leading cause (after habitat fragmentation) of global biodiversity loss (Wilcove et al. 1998; Bellard et al. 2016) and the major cause of species extinction in island ecosystems (Brockie et al. 1988; Tershy et al. 2002), the biological invasion has emerged as a gruelling challenge for the conservation managers.

Naturalists have observed the phenomenon of invasion since ages and invasive species were described by several nineteenth- and twentieth-century scientists, e.g. Charles Darwin, Alphonse De Candolle, Joseph Hooker, Charles Lyell, Frank Egler, Herbert Baker, Marston Bates, and Carl Huffaker (Richardson and Pyšek 2008; Richardson 2011). However, the precise concept of biological invasion was introduced by British ecologist, *Charles S. Elton* in 1958 in his book, *The Ecology of Invasions by Animals and Plants* (Elton 1958). He, therefore, is considered the

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unofficial Father of Invasion Ecology and his book is now accepted as a landmark in the field of invasion science (Davis et al. 2001). However, it was in 1982, during the general assembly of the Scientific Committee on Problems of the Environment (SCOPE), that a project named *SCOPE Programme on the Ecology of Biological Invasions* was initiated. This step provided momentum to the notion of biological invasion, resulting in a series of publications and regional/global synthesis associated with the concept (Simberloff 2011). Later, with the participation of the International Union for Conservation of Nature (IUCN) and the Centre for Agriculture and Bioscience International (CABI), *Global Invasive Species Programme* (*GISP*) was developed in 1997 (GISP 2020). This program addressed the factors driving the phenomenon of biological invasion, suggested prevention/management strategies, and developed a database for information exchange among researchers and conservation managers (Richardson 2011; GISP 2020).

At present, the growing attention towards this global problem can be estimated from (1) increased rate of publications/books on biological invasion; (2) scientific journals exclusively dedicated to tackling problems related with the issue (e.g. *Biological Invasions*, *Aquatic Invasions*, *NeoBiota*, *Bio-Invasions Records*); (3) conferences aiming to bring together the invasion biologists on a common platform (e.g. International Conference on Marine Bio-invasions; NeoBiota—European Conference on Biological Invasions), and (4) International Research Programmes such as GISP (1997), NEOBIOTA (1999), DAISIE (2005), INVASIVES (2013), GloNAF (2015), etc. addressing this issue on a global level (Canning-Clode 2015). Further, protocols such as Invasive Species Environmental Impact Assessment (ISEIA) and Environmental Impact Classification for Alien Taxa (EICAT) allow the classification of alien and invasive species under different risk categories (Vanderhoeven et al. 2017).

Furthermore, with the development of advanced techniques, molecular approaches, and DNA tools, a better understanding of the origin, evolution, and consequences of biological invasions is being captured (Ward et al. 2008; Darling et al. 2017). Attempts have also been made to forecast the spatio-temporal distribution of non-indigenous species in future climate change scenarios. Such studies can make reliable and robust predictions about population dynamics, potential outcomes, and preventive measures of the invasive species (Gallien et al. 2010). Nevertheless, invasion science has now become an independent sub-discipline of ecology (Davis et al. 2001). It has not only embraced a full spectrum of interdisciplinary fields, e.g. sociology, economics, and risk assessment but has also attracted socio-ecological collaborations amongst researchers, government bodies, non-government organizations, conservationists, landscape managers, and stakeholders (Canning-Clode 2015; Vaz et al. 2017).

In this chapter, we addressed the concept of *plant invasion* and the challenges associated with it. Beginning with the course of establishment of an alien plant into a new geographic range and the attributes which could facilitate its successful invasion in a non-native environment, this discussion aimed at enhancing the understanding of the phenomenon of plant invasion. Later on, the current status of invasive plant species at a regional and global scales is presented along with their consequences, which highlights the issues we are dealing with at present. Finally, we concluded the chapter by focusing on the potential risks that we are needed to be prepared for in near future.

19.2 Process of Plant Invasion

The framework of the invasion process and the associated terminologies are explained by a number of biologists (Williamson and Fitter 1996; Richardson et al. 2000; Blackburn et al. 2011). However, in a botanical context, the Richardson framework fits most appropriately (Blackburn et al. 2011). Here, an overview of the invasion process is provided in a generalized manner, taking insights from the model proposed by Richardson et al. (2000).

- The first stage of the invasion process requires the transportation of a plant or its propagule across the major geographical barrier(s) (inter-continental or intra-continental or both) through any agency (mostly humans, but there can be other factors such as wind, water, etc.). The species can be called "*alien*," "*exotic*," "*non-native*," "*non-indigenous*," and "*introduced*" (terminologies are interchangeably used by the researchers) at this step of the invasion process (Fig. 19.1).
- Upon introduction, the first and foremost challenge faced by an alien species is the novel environment (consisting of biotic/abiotic components) of the introduced habitat that a species needs to be acclimatized to for its survival (Fig. 19.1).
- Thereafter, a species needs to overcome any barrier(s) guarding the long-term and consistent production of offspring (either by vegetative or generative means). A species can be considered either "*casual*" or "*naturalized*" at this stage of the invasion process. The casuals are defined as the introduced species that can successfully survive and occasionally reproduce; however, they are incapable

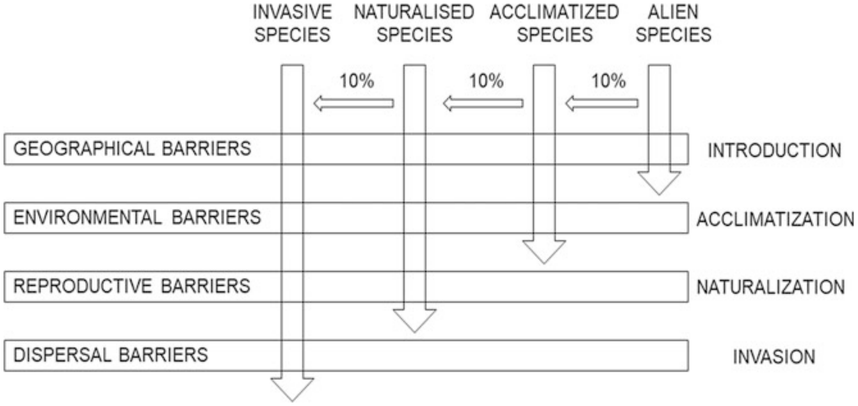

Fig. 19.1 A general scheme of the process of plant invasion (after Williamson and Fitter 1996; Richardson et al. 2000)

of producing self-replacing populations, and therefore, rely on repeated introductions for their existence within the non-native boundaries. On the contrary, naturalized plants are competent enough to reproduce on their own, freely, and for several generations (with or without human intervention) (Fig. 19.1).
- Finally, the naturalized species that produce offspring by generative means in hefty numbers and surmount the local/regional dispersal barriers, thereby spreading at considerable distances from parent plants, are called "*invasive*" (Fig. 19.1).

In addition to the given stages of invasion process, Richardson et al. (2000) further added post-dispersal environmental barriers (disturbed habitats and natural/ semi-natural habitats) to include the resistance posed by various factors during disturbances and process of succession. The authors also pointed out that the process is reversible, and any ecological shift or fluctuation may augment the spread of an alien species or result in its total extinction.

The statistical rule proposed by Williamson and Fitter (1996) is also explicitly and implicitly adopted by invasion biologists regardless of the identity of the taxon. The rule (popularly known as "*Ten's rule*") states that only one-tenth of the species (i.e. 10% of the total species) survive at every step of the invasion process (Fig. 19.1). Nevertheless, ecologists also have a contradictory viewpoint in this regard that the rule undermines the negative impacts posed by alien species that are still in the process of invasion (Jarić and Cvijanović 2012).

19.3 Determinants of Successful Invasion

The introduction-naturalization-invasion continuum depends upon interactions amongst the introduced species, the invaded habitat, and the chance/timing of introduction (Pyšek and Richardson 2008; Moravcová et al. 2015). Researchers argue that apart from these factors, the species of the invaded ecosystem and their interactions with the introduced species also regulate the trend of invasion (Szabó et al. 2019). Efforts are being made to provide the best explanation of the mechanisms underlying the invasion process. Several hypotheses have been proposed in this context, a few of which even reflect contradictory opinions (Enders et al. 2018). It has also been accepted that multiple factors govern the phenomenon of invasion and success of an invasive species and does not rely on any single theory/concept (Gurevitch et al. 2011). Common hypotheses/theories proposed so far in the context of plant invasion are listed in Table 19.1.

The dominance of an invasive species can be explained by one or more of these hypotheses. However, there could be many more factors that have not been included in these assumptions and yet have a strong influence on the invasion facet of a species. Also, there are aspects that have been postulated but deserve more consideration, understanding, and pragmatic evidence.

Table 19.1 Common hypotheses/theories proposed in context of plant invasion

Theory/hypothesis	Postulations	References
Disturbance	Disturbed ecosystems are more likely to attract invasions by alien species compared with the undisturbed ecosystems	Elton (1958), Hobbs and Huenneke (1992)
Diversity, Invasion Potential, or biotic resistance	The communities rich in biodiversity limit invasion By alien species compared with the communities where diversity is sparse	Elton (1958), Levine and D'Antonio (1999)
Enemy release	The absence of natural enemies (pests, pathogens, and predators) in the introduced region facilitates unchecked proliferation of the alien species	Elton (1958), Keane and Crawley (2002)
Ideal weed	Specific traits possessed by an alien species define its success in the non-native range	Elton (1958), Rejmánek and Richardson (1996)
Limiting similarity	Greater the difference between native and exotic species, greater will be the chances of invasion by the species	MacArthur and Levins (1967)
Empty niche or opportunity windows	Available resources or empty niches attract invaders to establish and propagate	MacArthur (1970), Johnstone (1986)
Dynamic equilibrium	Dynamic conditions of a habitat alter the competition of resident species and give way to the opportunistic alien invasive species	Hutson (1979)
Evolution of increased competitive ability	In case of reduced herbivory (due to the absence of natural enemies) in the introduced region, invasive plants tend to allocate their resources towards higher growth rate and better competitive ability rather than defence purposes	Blossey and Nötzold (1995)
Phenotypic plasticity	Alteration of phenotypic characteristics in response to environmental factors enables invasive plant species to perform better in a wide range of novel habitats	Williams et al. (1995)
Propagule pressure	Ability of an invasive species to produce long-lasting viable seeds provides it with a competitive advantage over the natives	Williamson (1996), Lockwood et al. (2013)
Invasional meltdown	Invaders affect ecosystem in a way to facilitate invasion by other alien species	Simberloff and von Holle (1999), Sax et al. (2007)
Sampling	A large number of different alien species in an area exert more interspecific competition for the natives, and hence tend to become more successful	Crawley et al. (1999)
Fluctuating resource	A decrease in native population due to any natural/anthropogenic disturbance opens up wealth of resources, and hence paves the way for invasion	Davis et al. (2000)
Adaptation	Alien species pre-adapted to ecological conditions of the invaded habitat or alien species closely related to the native species are more likely to become invasive	Duncan and Williams (2002)

(continued)

Table 19.1 (continued)

Theory/hypothesis	Postulations	References
Enemy inversion	Natural enemies of an invasive species introduced in the exotic ranges as biocontrol agents may not be as effective as they are in native ranges due to the novel ecological conditions of the invaded ecosystem	Colautti et al. (2004)
Increased susceptibility	The probability of exotic species with the lower genetic diversity to become invasive is low	Colautti et al. (2004)
Novel weapon	Allelochemicals released by an invasive plant species mediate new plant–plant and plant–microbial interactions, thus altering ecosystem functions	Callaway and Ridenour (2004)
Reckless invader	An alien species that become invasive soon after its introduction has a short success story and gets eliminated sooner or later	Simberloff and Gibbons (2004)
Specialist–generalist	Ecosystems, where local pests and predators are specialists and local mutualists are generalists, are more prone to invasion	Callaway et al. (2004)
Biotic acceptance	Despite being occupied by rich and diverse native communities, an invaded ecosystem tends to accept and accommodate the population of alien species	Stohlgren et al. (2006)
Enemy of my enemy	Natural enemies of an invasive species introduced in the exotic ranges as biocontrol agents are more harmful to native diversity of invaded ecosystem	Eppinga et al. (2006)
Human commensalism	Humans are not only responsible for introduction of alien species but also for their spread to long distances, thus facilitating the invasion process	Jeschke and Strayer (2006)
Environmental heterogeneity	Invasion by any alien species depends on heterogeneity of the host environment	Melbourne et al. (2007)
Island susceptibility	Island ecosystems are more prone to the attack and impacts of alien invasive species compared with the continental ecosystems	Jeschke (2008)
Community ecology	Introduced species with advanced phenologies are more likely to get adapted to the novel habitats, especially in view of seasonal shifts	Wolkovich and Cleland (2011)

19.4 Data on Invasive Alien Plants

Invasive alien plants are present in every part of the world; however, the numbers vary from region to region (Inderjit et al. 2018). The highest numbers of naturalized alien plants are documented from North America (~6000) and Europe (~4000); whereas, the lowest numbers are reported from Antarctica (~160), followed by temperate Asia (~2200) and tropical Asia (~2000 species) (van Kleunen et al. 2015). However, considering the fact that the majority of the global biodiversity is yet to be explored, it is expected that the actual number of the alien or invasive species are far more different than our current speculations (Jarić et al. 2019). This is particularly true for the emerging economies, where there is a lack of research opportunities and facilities.

19.4.1 International Statistics

Nearly one-sixth of the world's geographical area, including 16% of the global biodiversity hotspots, is predicted to be susceptible to invasion (Early et al. 2016). A global study by van Kleunen et al. (2015) anticipated that a total of 13,168 vascular plant species (approximately 3.9% of the world's total extant flora) have naturalized in 843 continental and island regions. The authors also stated that North America held the maximum naturalized flora, whereas Pacific Islands showed the maximum rate of accumulation of alien species (van Kleunen et al. 2015). Another report on naturalized alien flora of the world corroborated this study stating that California, North America, is the world's richest region in terms of naturalized alien flora with 1753 alien plant species (Pyšek et al. 2017).

The majority of the world's worst invasive plants belong to a relatively few families (Asteraceae, Poaceae) and genera (*Acacia*, *Mimosa*, *Cyperus*) (Mack et al. 2000). A recent study also confirmed the maximum contribution of Asteraceae (1343 species) to the global naturalized alien flora, followed by Poaceae (1267 species) and Fabaceae (1189 species) (Pyšek et al. 2017). On the contrary, this new report suggests *Solanum* (112 species), *Euphorbia* (108 species) and *Carex* (106 species) to be the most representative genera of the world's naturalized alien plant community (Pyšek et al. 2017). It has also been ascertained that horticulture and nursery trade are the main pathways for intentional plant introductions, whereas ignorant possessions and transportation are accounted for the maximum unintentional introductions (Turbelin et al. 2017). GISD (2020) lists 100 worst invasive species of the world, of which 36 are invasive plant species (Table 19.2).

19.4.2 National Statistics

Estimations about the share of alien or invasive species in the Indian vegetation over the last ten years have varied to a great extent. In an earlier report, Reddy (2008) described 173 species consisting of 117 genera and 44 families to be invasive in India. Later on, another study revealed that exotic species constitute 8.5% (1599 species) of the net extant vascular flora of the country with 14% (225 species) being invasive (Khuroo et al. 2012). Of late, a total of 471 naturalized alien species were reported in India, representing 2.6% of the total flora of India (Inderjit et al. 2018).

Table 19.2 Worst invasive plant species of the world (source: CABI 2020; GISD 2020; GRIN 2020; Plant List 2020)

Plant species	Family	Habit	Nativity	Distribution
Terrestrial plants				
Acacia mearnsii De Wlid.	Fabaceae	Shrub/ tree	Aus	Afr; Eur; Pac; S Am
Ardisia elliptica Thunb.	Primulaceae	Shrub	Asia temp; Asia trop	Afr; N Am; Pac; S Am
Arundo donax L.	Poaceae	Grass	Asia temp; Asia trop	Afr; Aus; Eur; N Am; Pac; S Am
Cecropia peltata L.	Urticaceae	Tree	N Am; S Am	Afr; Asia trop; Pac
Chromolaena odorata (L.) R.M. King and H. Rob.	Asteraceae	Herb	N Am; S Am	Afr; Asia temp; Asia trop; Aus
Cinchona pubescens Vahl	Rubiaceae	Tree	S Am	Afr; Pac
Clidemia hirta (L.) D. Don	Melastomataceae	Shrub	N Am; S Am	Paleotropics
Euphorbia esula L.	Euphorbiaceae	Herb	Afr; Asia temp; Asia Trop	N Am; Eur
Hedychium gardnerianum Sheppard ex Ker Gawl.	Zingiberaceae	Herb	Asia trop	Afr; Aus; Pac; S Am
Hiptage benghalensis (L.) Kurz	Malpighiaceae	Shrub	Asia temp; Asia trop	Afr; Aus; Pac; N Am
Imperata cylindrica (L.) Raeusch.	Poaceae	Grass	Afr; Asia temp; Asia trop; Aus; Eur	Pac; N Am; S Am
Lantana camara L.	Verbenaceae	Shrub	N Am; S Am	Neotropics
Leucaena leucocephala (Lam.) de Wit	Fabaceae	Tree	N Am; S Am	Afr; Asia trop; Asia temp; Aus; Eur; Pac
Ligustrum robustum (Roxb.) Blume	Oleaceae	Shrub/ tree	Asia trop; Asia temp	Afr; N Am
Lythrum salicaria L.	Lythraceae	Herb	Afr; Asia temp; Eur	Aus; N Am; S Am
Melaleuca quinquenervia (Cav.) S.T.Blake	Myrtaceae	Tree	Asia trop; Aus; Pac	Afr; N Am; S Am
Miconia calvescens DC.	Melastomataceae	Tree	N Am; S Am	Asia trop; Aus; Pac
Mikania micrantha Kunth	Asteraceae	Climber	N Am; S Am	Afr; Asia trop; Asia temp; Aus; Pac
Mimosa pigra L.	Fabaceae	Shrub	Afr; N Am; S Am	Asia trop; Aus; Pac
Myrica faya Dryand.	Myricaceae	Tree	Afr	Pac

(continued)

Table 19.2 (continued)

Plant species	Family	Habit	Nativity	Distribution
Opuntia stricta (Haw.) Haw.	Cactaceae	Shrub	N Am; S Am	Afr; Asia temp; Aus; Eur; Pac
Pinus pinaster Aiton	Pinaceae	Tree	Afr; Eur	Afr; Aus; Pac; S Am
Prosopis glandulosa Torr.	Fabaceae	Tree	N Am	Afr; Aus; S Am
Psidium cattleianum Afzel. ex Sabine	Myrtaceae	Shrub	S Am	Afr; Aus; N Am; Pac
Pueraria montana var. lobata (Willd.) Sanjappa & Pradeep	Fabaceae	Climber	Asia temp; Asia trop; Pac	Afr; Aus; Eur; N Am; S Am
Reynoutria japonica Houtt.	Polygonaceae	Herb	Asia temp	Aus; Eur; N Am; S Am
Rubus ellipticus Sm.	Rosaceae	Shrub	Asia temp; Asia trop	Afr; Aus; Pac; S Am
Schinus terebinthifolia Raddi	Anacardiaceae	Shrub/ tree	S Am	Afr; Aus; Eur; N Am; Pac
Spathodea campanulata P. Beauv.	Bignoniaceae	Tree	Afr	Asia trop; Aus; Pac; S Am
Sphagneticola trilobata (L.) Pruski	Asteraceae	Herb	N Am; S Am	Afr; Asia temp; Asia trop; Aus; Pac
Tamarix ramosissima Ledeb.	Tamaricaceae	Shrub/ tree	Asia temp; Asia trop	Afr; N Am; S Am
Ulex europaeus L.	Fabaceae	Shrub	Eur	Afr; Asia temp; Asia trop; Aus; N Am; S Am
Aquatic plants				
Caulerpa taxifolia (M. Vahl) C.Agardh	Caulerpaceae	Green Macro-alga	Tropical waters of the Indian, Pacific and Atlantic Oceans	The Mediterra-nean Sea
Eichhornia crassipes (Mart.) Solms	Pontederiaceae	Herb	S Am	Tropics and subtropics
Spartina anglica C.E. Hubb.	Poaceae	Grass	Eur	Asia temp; Aus; N Am
Undaria pinnatifida (Harvey) Suringar	Alariaceae	Kelp	Asia temp; Asia trop	Eur; N Am; S Am; Aus

Nativity: *Afr* Africa, *Asia trop* Asia tropical, *Asia temp* Asia temperate, *Aus* Australia, *Eur* Europe, *S Am* South America, *N Am* North America, *Pac* Pacific Islands

This report also stated that lower altitudinal regions lying in tropical/subtropical areas have greater number of alien flora with the maximum figures being recorded from Tamil Nadu (332 species) and the minimum being recorded from the Lakshadweep Islands (17 species) (Inderjit et al. 2018).

A survey of the Indian Himalayan Region showed the presence of 571 alien species, of which 21% (96 species) were invasive (Khuroo et al. 2007). Another study described a total of 190 invasive alien species from the Indian Himalayas representing 112 genera and 47 families (Sekar 2012). On the other hand, a study of the Srinagar city revealed a higher percentage of alien species (58%) rather than natives (48%) in the local vegetation (Mehraj et al. 2018). It has also been observed that the richness of alien species plunged rapidly above an altitude of 2000 m asl (Khuroo et al. 2011). In an attempt to identify the invasion hotspots in India using the approach of Ecological Niche Modelling, it was predicted that nearly 49% of the total geographical area and 19 of the total 47 eco-regions of the country are susceptible to invasion with biodiversity hotspots and coastal areas being the most sensitive regions (Adhikari et al. 2015).

Similar to the data reported at the global scale, the most representative families of naturalized Indian flora are Asteraceae, Fabaceae, and Poaceae (Khuroo et al. 2012; Inderjit et al. 2018). However, the Indian Himalayan region is also dominated by Solanaceae, Convolvulaceae, and Brassicaceae (Khuroo et al. 2007; Sekar 2012). As per the previous findings of Khuroo et al. (2012), the three most species-rich genera were *Eucalyptus*, *Ipomoea*, and *Senna*; whereas according to the recent data, *Solanum*, *Ipomoea*, and *Euphorbia* are the dominating genera of the alien flora of India (Inderjit et al. 2018). The most obnoxious alien invasive species of the country include *Parthenium hysterophorus*, *Ageratum conyzoides* L., *Lantana camara* L., *Chromolaena odorata* (L.) R.M.King & H.Rob., *Ageratina adenophora* (Spreng.) R.M.King & H.Rob., *Leucaena leucocephala* (Lam.) de Wit, *Prosopis juliflora* (Sw.) DC. and *Mikania micrantha* Kunth among the terrestrial exotics and *Eichhornia crassipes* (Mart.) Solms and *Pistia stratiotes* L. among the aquatic exotics (Sharma and Raghubanshi 2012). Some of the alien plants, notably, *Tagetes minuta* L., *Anthemis cotula* L., *Sapium sebiferum* (L.) Roxb. and *Broussonetia papyrifera* (L.) L'Hér. ex Vent. are in the process of establishment and hold the potential to become invasive in future (Kohli et al. 2012). Biogeographically, the majority of the alien flora of the country is native of the USA (Khuroo et al. 2012; Sekar 2012; Inderjit et al. 2018). A list of troublesome invasive alien plant species of India is presented in Table 19.3.

19.5 Ecological and Socio-economic Implications of Plant Invasion

The establishment of invasive plants not only poses a threat to the ecosystem processes and natural biodiversity but also affect important socio-economic assets (Lazzaro et al. 2020). Exact estimates of the damage imposed by invasive plants on the invaded habitat are difficult to gauge; however, monetary losses via disruption of ecosystem services and socio-economic provisions, and imposition of management efforts may be determined. Furthermore, invasion dynamics are rapidly changing

Table 19.3 A list of major invasive alien plant species of India (source: CABI 2020; GRIN 2020; NBA-MoEF & CC 2020; Plant List 2020)

Plant species	Family	Habit
Terrestrial plants		
Acacia auriculiformis Benth.	Fabaceae	Tree
Acacia dealbata Link	Fabaceae	Shrub/tree
Acacia mearnsii De Wlid.	Fabaceae	Shrub/tree
Ageratina adenophora (Spreng.) R.M.King and H.Rob.	Asteraceae	Herb
Ageratina riparia (Regel) R.M.King and H.Rob.	Asteraceae	Herb/shrub
Ageratum conyzoides L.	Asteraceae	Herb
Alternanthera bettzickiana (Regel) G.Nicholson	Amaranthaceae	Herb
Alternanthera brasiliana (L.) Kuntze	Amaranthaceae	Herb
Alternanthera ficoidea (L.) Sm.	Amaranthaceae	Herb
Alternanthera paronychioides A.St.-Hil.	Amaranthaceae	Herb
Alternanthera pungens Kunth	Amaranthaceae	Herb
Antigonon leptopus Hook. and Arn.	Polygonaceae	Climber
Argemone mexicana L.	Papaveraceae	Herb
Bidens pilosa L.	Asteraceae	Herb
Cannabis sativa L.	Cannabaceae	Herb
Centrosema molle Benth.	Fabaceae	Herb
Cestrum aurantiacum Lindl.	Solanaceae	Shrub
Chromolaena odorata (L.) R.M.King and H.Rob.	Asteraceae	Herb
Cirsium arvense (L.) Scop.	Asteraceae	Herb
Cryptostegia grandiflora Roxb. ex R.Br.	Apocynaceae	Climber
Cuscuta chinensis Lam.	Convolvulaceae	Climber
Cytisus scoparius (L.) Link	Fabaceae	Shrub
Dactyliandra welwitschii Hook.f.	Cucurbitaceae	Climber
Dinebra retroflexa (Vahl) Panz.	Poaceae	Grass
Dysphania ambrosioides (L.) Mosyakin and Clemants	Amaranthaceae	Herb
Erigeron bonariensis L.	Asteraceae	Herb
Erigeron canadensis L.	Asteraceae	Herb
Evolvulus nummularius (L.) L.	Convolvulaceae	Herb
Herissantia crispa (L.) Brizicky	Malvaceae	Herb
Hyptis suaveolens (L.) Poit.	Lamiaceae	Herb
Ipomoea eriocarpa R. Br.	Convolvulaceae	Climber
Ipomoea fistulosa Mart. ex Choisy	Convolvulaceae	Climber
Lantana camara L.	Verbenaceae	Shrub
Lepidium didymum L.	Brassicaceae	Herb
Leptochloa fusca (L.) Kunth	Poaceae	Grass
Leucaena leucocephala (Lam.) de Wit	Fabaceae	Tree
Maesopsis eminii Engl.	Rhamnaceae	Tree
Mikania micrantha Kunth	Asteraceae	Climber
Mimosa diplotricha Sauvalle	Fabaceae	Shrub
Mimosa pigra L.	Fabaceae	Shrub
Muntingia calabura L.	Mutingiaceae	Tree

(continued)

Table 19.3 (continued)

Plant species	Family	Habit
Opuntia dillenii (Ker Gawl.) Haw.	Cactaceae	Shrub
Opuntia elatior Mill.	Cactaceae	Shrub
Parthenium hysterophorus L.	Asteraceae	Herb
Pennisetum purpureum Schumach.	Poaceae	Grass
Prosopis juliflora (Sw.) DC.	Fabaceae	Tree
Pueraria montana var. lobata (Willd.) Sanjappa and Pradeep	Fabaceae	Climber
Senna spectabilis (DC.) H.S.Irwin & Barneby	Fabaceae	Tree
Solanum elaeagnifolium Cav.	Solanaceae	Herb
Solanum mauritianum Scop.	Solanaceae	Shrub/tree
Sphagneticola trilobata (L.) Pruski	Asteraceae	Herb
Ulex europaeus L.	Fabaceae	Shrub
Aquatic plants		
Alternanthera philoxeroides (Mart.) Griseb.	Amaranthaceae	Herb
Cabomba caroliniana A.Gray	Cabombaceae	Herb
Eichhornia crassipes (Mart.) Solms	Pontederiaceae	Herb
Ipomoea carnea Jacq.	Convolvulaceae	Shrub
Lemna perpusilla Torr.	Araceae	Herb
Lythrum salicaria L.	Lythraceae	Herb
Marsilea quadrifolia L.	Marsileaceae	Herb
Myriophyllum aquaticum (Vell.) Verdc.	Haloragaceae	Herb
Salvinia adnata Desv.	Salviniaceae	Herb
Typha angustifolia L.	Typhaceae	Herb

over time due to globalization (Meyerson and Mooney 2007). Thus, it is even more complicated to predict the ecological and economic costs of invasion in the future scenario.

19.5.1 Ecological Impacts

The impact of invasive plant species on community structure (via an effect on plant communities and higher trophic levels) and ecosystem processes (via interference in natural biotic/abiotic interactions, soil chemistry, nutrient cycling, hydrology, fire regimes, and other microclimatic conditions) is quite evident (Mack et al. 2000; Levine et al. 2003). Invasive alien plants have altered the ecological landscapes, degraded the ecosystem services, threatened the existence of native species, and triggered the homogenization of the world's biota, both in terrestrial and aquatic ecosystems (Vilà et al. 2011). In the forest ecosystems, certain additional threats are experienced such as the risk of hybridization, the transmission of diseases, and interference with forest regeneration (Langmaier and Lapin 2020). However, these impacts are strongly context-dependent and vary depending upon the characteristics

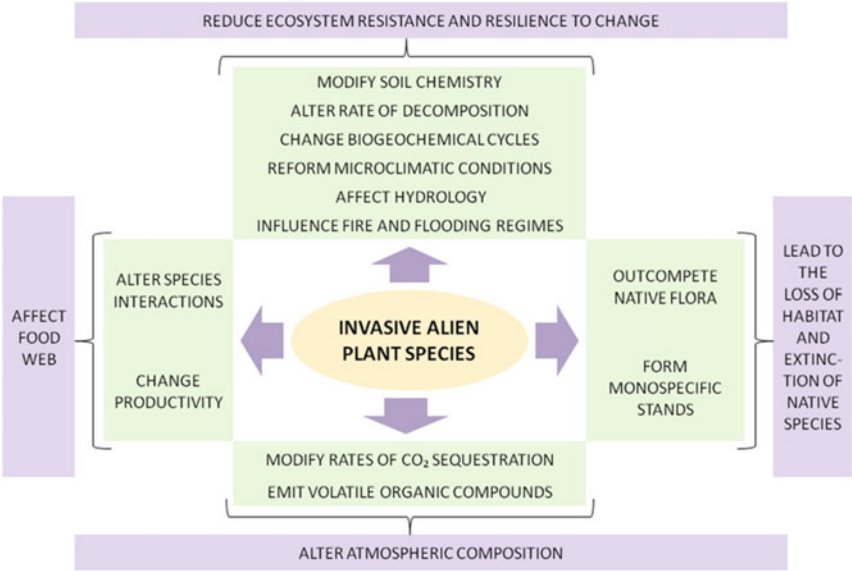

Fig. 19.2 Diagrammatic representation of the ecological impact of invasive alien plants

of invasive species and invaded habitat (Pyšek et al. 2012). A diagrammatic representation provided in Fig. 19.2 describes the multitude of ecological impacts inflicted by invasive alien species on an invaded landscape.

Statistical figures representing the extent to which invasive plant species pose a threat to the native biodiversity are severely lacking; however, some regional examinations provide interesting insights. Researchers argue that alien plants are more likely to cause displacement and community change rather than species extinctions. However, allying with natural/anthropogenic disturbances, these declined the population of 410 of the 602 plant species and 19 of the 68 bird species in the USA (Gurevitch and Padilla 2004). Threatened by the continuous spread of alien plants, nearly 166 and 113 indigenous plant species of New South Wales are listed as Endangered and Vulnerable, respectively, which together represent 49% (279 of 565) of the indigenous flora of the region (Coutts-Smith and Downey 2006). A recent study suggested that alien invasive species (here, both plant and animal invasions were taken into consideration) are responsible for 27% of the Extinct (EX)/ Extinct in wild (EW) plant taxa (as per IUCN Red List 2015), all of which were island endemic species (Bellard et al. 2016). Downey and Richardson (2016) suggested that interventions of alien flora may not directly lead to extinction, but is evidently responsible for altering the extinction trajectory of species, and conservation managers should take into account the issue of alien invasions before further extinctions happen.

19.5.2 Socio-economic Impacts

Invasive plants pose a significant threat to agriculture, forestry, fisheries, and other human enterprises (Bhowmik 2005). Many invasive plants are noxious weeds of important food and cash crop species such as *P. hysterophorus*, *A. conyzoides*, *Echinochloa crus-galli* (L.) P.Beauv., *Striga hermonthica* (Delile) Benth., *Datura ferox* L., *Pennisetum* spp., *Amaranthus* spp., *Chromolaena* spp., *Cyperus* spp., and *Digitaria* spp., etc. Invasive weeds are usually more adaptable, capable of generating a large propagule pressure, tolerant to different biotic/abiotic stresses, and extremely competitive for resources (Bhowmik 2005). As a result, they compete aggressively with the crop species and cause substantial yield loss.

Similarly, invasive plant species may also lead to enormous economic losses by jeopardizing ecosystem services (Szabó et al. 2019). The habitats drifted towards invasion and were found to lose the native species, which used to provide basic food, fodder, fuel, and medicinal services to the locals (Kohli et al. 2006). Invasion of rangelands by exotic plant species reduces the availability of grasses and forbs for the livestock which has affected the practice of animal husbandry (O'Connor and van Wilgen 2020). Several other provisions substantial to human life, such as water resources, pollination services, wildlife-based tourism, and recreational activities are directly or indirectly influenced by the spread of exotic plant species (O'Connor and van Wilgen 2020). In addition, various human health hazards could also be a possible outcome of plant invasion. Some of the invasive plants have direct implications on human health (allergies, skin diseases, respiratory problems, etc.), while others influence indirectly via transmission of pests that cause diseases in humans (Allan et al. 2010).

Thereafter, the management of invasive species attracts huge finances that sometimes may not even fit in the budget of countries with low economies. The United States inhabits nearly 5000 invasive plants incurring annual monetary losses of up to $35 billion (Pimentel et al. 2005). A report from South Africa stated that an amount of nearly $38 million was spent to control alien plants in the protected areas of the Cape Floristic Region and $11–$175 million will be required in the future to address the issue (van Wilgen et al. 2016). Data on the expenditure required to control invasive plants are largely unavailable and close estimations are nearly impossible to draw. However, considering the current situation and future environmental challenges, it can be safely predicted that these figures are going to be raised exponentially to keep invasive plants in check in the near future.

19.6 Potential Risks and Future Challenges Associated with Invasive Alien Plants

Invasion dynamics are shifting at a much faster pace because of various natural and anthropogenic factors, namely, climate warming, enhanced nitrogen deposition, increased carbon dioxide concentrations, deforestation, habitat fragmentation, changes in land use pattern, population explosion, and rapid economic development (Hobbs 2000; Lin et al. 2007; Meyerson and Mooney 2007; He et al. 2011; Carboni et al. 2018). Consequently, the risks and challenges associated with the invasive alien plants are also multiplying. From the increased aggressiveness of the established invasive species to the constant emergence of new invasive species, the issues in invasion science are getting gruelling and worrisome.

The leading challenge in front of conservation ecologists, both from present and future perspective is the management of invasive plant species. Although the management strategies depend largely on the characteristics of invasive species and the invaded habitat, yet there are certain key points applicable in general. It has been well established that multiple factors govern the invasion success of an alien species and understanding these factors is a pre-requisite for designing any management program (Pyšek et al. 2012; Szabó et al. 2019). Thus, there is a strong need to bridge the knowledge gaps that persist in the understanding of invasion mechanisms. Apart from that, the choice of a strategy should take into consideration the long-term implications, involvement of a wide range of participants (from researchers to government and non-governmental organizations to local people), a suitable and balanced budgeting, and an assured consistency of efforts. Integrated weed management, a strategy that uses a combination of different control methods in an appropriate fashion, is the best approach to monitoring and regulating any invasive plant. Researchers also suggest utilizing the invasive species for ecological and economic purposes instead of the native flora (Huang et al. 2014; Carson et al. 2018). This is a relatively new and better alternative that can attract the involvement of diverse groups, industries, and the general public. Awareness among local people is another important issue that should be duly considered. Although most people do not oppose the management of invasive species, such actions are, however, not perceived as a high priority and sometimes may even be opposed (if an invasive species is providing ecosystem services or is of ornamental value) (Potgieter et al. 2019). Greater environmental awareness among people, particularly the youngsters, is of utmost importance, as this will not only aid the implementation of control strategies but will also ensure the success of the program.

Another crucial challenge is to identify the naturalized species which hold the potential to become invasive in the near future. Such species may already be in their lag phase and preparing to turn invasive or may get triggered by climate warming, seasonal shifts, or any other disturbances in the ecosystem to become invasive. In this case, identification of alien flora and constant monitoring of the species, which are either close relatives of the established invasive species or characteristically identical to them, might be helpful. Species that have a history of invasion in other parts of the world should also be targeted. At the same time, it is important to identify the geographic ranges and habitats which are more susceptible to invasion, so that appropriate preventive measures can be undertaken for their protection. Prior knowledge of the traits of most successful invasive species can also have long-term implications such as understanding of universal invasive attributes, prediction of prospective niches for an invasive species, and identification of potential invaders (Gallagher et al. 2015).

Last but not the least, it is crucial to establish strong quarantine measures to restrict the unintentional introduction of alien plants from one geographic region to another. Food and Agriculture Organization (FAO) introduced an intergovernmental treaty *International Plant Protection Convention (IPPC)* signed by 180 member countries in 1951, with an objective to "protect world's plant resources from the spread and introduction of pests and promote safe trade" (FAO 2020). The treaty is governed by certain guidelines to prevent the entry, establishment, and spread of exotic plant pests (including weeds). Although the plant quarantine measures are followed by most of the member countries, they are not stringent enough to completely restrain the unintentional transport of plant/plant parts/seeds. On the other hand, the intentional introduction should only be allowed when absolutely necessary, and the species should undergo a well-established risk assessment protocol. Policymaking should involve both government officials and researchers so that the risk assessment system should be scientifically sound and unambiguous. Only the combined efforts in research and policymaking, and strict actions at legislative, technical, and administrative levels can facilitate the containment of potentially invasive plant species.

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Chapter 20
Alien Invasive Aquatic Fauna: Challenges and Mitigation

Kailash Chandra and Chelladurai Raghunathan

20.1 Introduction

The concern about nature and biodiversity-related issues and conserving them is a very recent addition in scientific knowledge due to various reasons like shrinkage of freshwater cover, climatic changes, ozone layer depletion due to carbon emission, habitat degradation, reduction of natural forest cover, overharvesting of natural resources, overexpanding population growth rate of humans, reduction of wildlife, etc. (Union of Concerned Scientists 1992; Pyšek et al. 2020). The decline of biodiversity due to Invasive Alien Species (IAS) was not paid much attention to till 1992, though it was listed as one of the major indicators of biodiversity decline in the world (Butchart et al. 2010). Ripple et al. (2017) mentioned the spreading of IAS as one of the stable and more prominent issues for the decline of biodiversity (Pyšek et al. 2020). The global data on biodiversity and its services analysed the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) and mentioned the IAS as one of the five direct influencers for biodiversity loss across the world (Brondizio et al. 2019; Pyšek et al. 2020).

Invasive Alien Species (IAS), also sometimes called exotic species, non-indigenous species, introduced species, non-native species, and allochthonous species (Corrales et al. 2019), have the capacity of greater survival beyond its natural and native biogeographic range. The spread of the species outside its normal geographical barrier may be seen as a past or recent event due to intentional or unintentional ways by means of natural or anthropogenic activities. The dispersal, spread, or introduction of the IAS can be found as the whole specimen or any part, eggs, propagules, seeds, etc. which resulted in high productivity along with a notable range of survivability (Essl et al. 2018; Corrales et al. 2019).

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20.2 Definition

The definitions of alien species and invasive alien species are made by several agencies, while the most accepted definitions are cited by CBD (2000) and International Union for Conservation of Nature. As per the Convention on Biological Diversity (CBD 2000), alien species defines "*species, subspecies or lower taxon, introduced outside its natural past or present distribution; including any part, gametes, seeds, eggs, or propagules of such species that might survive and subsequently reproduce*," while according to, "*an alien species which becomes established in natural or semi-natural ecosystems or habitat, is an agent of change, and threatens native biological diversity.*" In case of invasive alien species, CBD describes "*an IAS as an alien species whose establishment and spread threatens ecosystems, habitats or species with economic or environmental harm*," whereas, the as per the IUCN, it is noted that "*an IAS is an alien species which becomes established in natural or semi-natural ecosystems or habitats, is an agent of change, and threatens native biological diversity*." Any living organism under any taxon—belonging to animals, plants, fungi, or micro-organisms—may be considered as an invasive alien species if the existence of that species generates adverse impression on any ecosystem as well as its services beyond its natural native range (Dudgeon et al. 2006; Strayer 2010; Bellard et al. 2016; Maxwell et al. 2016; Magliozzi et al. 2020).

The process of bioinvasion or biological invasion is one of the potential threats due to alteration of the entire biodiversity as well as environmental conditions in any habitats like aquatic (freshwater, estuarine, and marine) and terrestrial regions (Corrales et al. 2019). The threats are documented in relation to the ecology and ecological services as well as economic loss, alteration of genetic diversity, depletion of native species population, including the higher risks of extinction and shift of the whole ecosystem (Grosholz 2002; Bax et al. 2003; Pejchar and Mooney 2009; Strayer 2010; Levin and Crooks 2011; Simberloff et al. 2013; Katsanevakis et al. 2014; Gallardo et al. 2016; Vilà and Hulme 2017; Corrales et al. 2019). As a whole, these species are the major cause of extensive threats to global biodiversity, followed by human health hazards (WRI 2005). The process of the bioinvasion is taking a noteworthy role for the alteration of the entire coordination of any ecosystem with the combination of other physical and ecological factors such as climatic conditions, level of pollution, degraded habitat, overexploitation rate, and has resulted as a crucial hassle on the new bio-network (Dudgeon et al. 2006; Halpern et al. 2015; Corrales et al. 2019). This chapter defines the details on the aquatic invasive alien species of faunal communities of India along with possible challenges and mitigation measures.

20.3 Routes of Invasion

The transportation services are recognized as the most proficient reason behind the spread of invasive alien species (IAS), either intentionally or unintentionally, as one of the major anthropogenic causes. The spread of the invasive species is extensively proportionally related with increased trades and transport facilities due to speedy globalization and resulted in the fast-tracked bioinvasion across the globe (Hulme 2009; Katsanevakis et al. 2013; Nunes et al. 2015; Seebens et al. 2017; Corrales et al. 2019). The trade of pets and plants is also considered as one of the major threats in the expansion of IAS, while stowaways in passenger planes are also recorded for the same (McCullough et al. 2006; Hulme et al. 2008; Essl et al. 2015). The global seaways movement is also known as the epicentre of bioinvasion as shipping services manage more than 80% trade measures across the world (Bax et al. 2003; McCullough et al. 2006; Bellard et al. 2016). The quantum of the seaways movement for trade is developing in a progressive manner, such as in 1970, it was 2490 million tonnes, while in 2000, it reached 5330 million tonnes (Bax et al. 2003). The ballast water is also known as a notable source of transportation of invasive alien species with around 10,000 species at a single time, including vectors, viral as well as bacterial pathogens (Carlton 1999; Thresher 1999, 2000; Ruiz et al. 2000; Bax et al. 2003). The overexpanding of trade across the globe through shipping increased the occurrence of ballast water movement also, with approximately 12 billion tonnes of water displaced annually from one geographical region to other (Bax et al. 2003). The hulls of the ships and sea chest are acknowledged as other potential factors for the transmission of IAS which are with fouling features (Bax et al. 2003). In recent times, some more routes of potential transmission, such as aquarium trade of the world, recreational water users, and the oil, gas, and construction industries were identified too (Bax et al. 2003). Hulme et al. (2008) demonstrated six major ways for the introduction of IAS, which includes a purposeful introduction; escape from ex situ condition; pollutants of merchandises; stowaways on conveyance systems; via man-made passages; and unintentional spread from other invaded areas (Pyšek, et al. 2020).

20.4 Aquatic Ecosystem

The studies on the IAS in aquatic ecosystem were emphasized very recently based on their quantum of damages. The initial focus was made to assess impacts of invasive alien species on the aquatic habitats up to 1992. The studies were gradually increased during nearly the last 15 years in comparison with previous years. The previous studies reveal that much emphasis was focused on the freshwater ecosystem, followed by the marine ecosystem and estuarine ecosystem, based on available published literature such as 75% (includes Nearctic, Palearctic, and Afrotropical zones), 22% (includes Temperate Northern Atlantic, Tropical Atlantic, and

Temperate Northern Pacific zones), and only 3%, respectively (Corrales et al. 2019), for the documentation of IAS. During the current scenario, studies on invasive alien species have been carried out across the world. The studies in Australian waters suggested the recording of a total of 252 IAS from marine and estuarine habitats, including introduced as well as cryptogenic species (Hewitt et al. 1999; Bax et al. 2003). A total of 159 marine invasive species were recorded from New Zealand waters (Cranfield et al. 1998; Bax et al. 2003). In the San Francisco Bay and Delta of California, a total of 212 invasive species were recorded from the marine ecosystem, while 91 species were found from Hawaii as invasive species (Cohen and Carlton 1998; Coles et al. 1999; Bax et al. 2003). In Europe, a total of 149 species are recorded as alien species (Pyšek et al. 2020). The recent studies made by IPBES indicated that the occurrence and reporting of the IAS per country drastically increased to 70% since 1970 (Brondizio et al. 2019; Pyšek et al. 2020). A total of 464 species of organisms, including 6 species of plants, 6 species of phytoplankton, and 452 species of faunal communities such as 5 species of parasites, 24 species of zooplankton, 2 species of bryozoans, 9 species of polychaetes, 3 species of barnacles, 117 species of molluscs, 2 species of ascidians, 16 species of ctenophores, 7 species of cnidarians, 13 species of shrimps, 14 species of crabs, 2 species of other benthic forms of crustaceans, 217 species of fishes, and 4 species of birds are recognized as IAS in aquatic ecosystems of the world (Corrales et al. 2019). Among the various sorts of aquatic ecosystems, freshwater ecosystem harbours 277 IAS, followed 173 IAS from marine ecosystem, while only 14 species are noticed from the estuarine ecosystem (Corrales et al. 2019).

20.5 Indian Scenario

The studies on the invasive alien species are scanty in the Indian context. Earlier studies were focused on the invasive amphipod species from the coastal waters of India by Sivaprakasam (1969, 1977). Karande and Menon (1975) and Santhakumaran (1976) made reports on the invasive molluscs from Indian waters. Rao and Ganapati (1978) reported fouling organisms as bio-invasive communities. Rajagopal (1997) investigated the invasive species, especially on the settlement pattern. Santhakumari (1997) studied the ecological aspects of some invasive species. Comprehensive studies were carried out on the invasive species by Anil et al. (2002, 2003), especially in the marine ecosystems. Soja (2006) and Soja and Menon (2009) reported bryozoans from Indian waters with biofouling capacity. Gaonkar et al. (2010) contributed extensively to the reporting of invasive species. Padmakumar et al. (2011) documented the invasive alien species, i.e. *Carijoa riisei* from the Gulf of Mannar followed by Divya et al. (2012) from the South Andaman region, whereas Raghunathan et al. (2013) mapped the same species from different areas of Indian waters. Galil et al. (2013) and Prasade et al. (2016) reported invasive species of scyphozoans from Indian waters. Prasade et al. (2015) documented a ctenophore species as invasive from Indian waters. Mankeshwar et al. (2015) studied the invasive bryozoans from Indian waters. Remarkable contributions on the exotic and invasive species of ascidians were carried out by Renganathan (1981, 1984), Meenakshi (2005, 2009), Jaffarali et al. (2009, 2010, 2015), Swami et al. (2011), Tamilselvi et al. (2011), Meenakshi and Senthamarai (2013), Jaffarali and Tamilselvi (2016), and Mondal et al. (2015, 2017) along with the identification of fouling capacity. Dev Roy and Nandi (2017) made some notable studies on the invasive crustaceans of Indian waters. As per the recent estimate, a total of 173 IAS are recorded from India, including 54 species of terrestrial plants, 56 species from aquatic ecosystem, 47 species from the agricultural ecosystem, and 14 species from the island ecosystem (Sandilyan 2019; ENVIS 2020).

20.6 Aquatic Invasive Alien Species in India

The comprehensive studies and data on available literature suggest that a total of 154 species of faunal communities, including 56 species from terrestrial and freshwater ecosystems and 98 species of marine ecosystems, are recorded from India as exotic/invasive species (Table 20.1). The aquatic ecosystem of India harbours

Table 20.1 Exotic/invasive alien species in aquatic ecosystems in India

Terrestrial and freshwater ecosystems

S. No.	Groups				Terrestrial ecosystem	Freshwater ecosystem	Total
1.	Arthropoda				31		31
2.	Pisces					19	19
3.	Reptilia					1	1
4.	Aves				3		3
5.	Mammalia				2		2
	Subtotal				*36*	*20*	*56*

Marine ecosystem

Sl. No.	Groups	West coast	East coast	Peninsular Indian coasts	All coasts, including islands	Indian waters *(no specific distribution record)*	Total
1.	Cnidaria	5	1	2	3		11
2.	Ctenophora	3					3
3.	Mollusca	2		2	1		5
4.	Annelida	13	1		1	1	16
5.	Arthropoda	8		4		14	26
6.	Bryozoa	2	2	2			6
7.	Entoprocta					1	1
8.	Ascidia	4	13	1	12		30
	Subtotal	*37*	*17*	*11*	*17*	*16*	*98*
	Grand total						*154*

118 species of invasive/exotic species across the country, including 98 species from the marine ecosystem and 20 species from the freshwater ecosystem.

20.7 Invasive Alien Species in Freshwater Ecosystem

A total of 20 species of faunal communities, including 19 species of freshwater fishes, especially on rivers and wetlands, and a reptile are reported as invasive and exotic species from inland waters of India (Table 20.2).

Table 20.2 Freshwater exotic/invasive alien species in India

S. No.	Species	Common name
	Fishes	
1.	*Carassius auratus* (Linnaeus, 1758)	Gold crucian carp
2.	*Cyprinus carpio* (Linnaeus, 1758)	Common carp
3.	*Ctenopharyngodon idella* (Valenciennes, 1844)	Grass carp
4.	*Hypophthalmichthys molitrix* (Valenciennes, 1844)	Silver carp
5.	*Hypophthalmichthys nobilis* (Richardson, 1845)	Bighead carp
6.	*Tinca* (Linnaeus, 1758)	Green tench
7.	*Piaractus brachypomus* (Cuvier, 1818)	Red-bellied pacu
8.	*Clarias gariepinus* (Burchell, 1822)	African sharptooth catfish
9.	*Pangasianodon hypophthalmus* (Sauvage, 1878)	Suchi pangas catfish
10.	*Pterygoplichthys disjunctivus* (Weber, 1991)	Vermiculated sailfin catfish
11.	*Pterygoplichthys multiradiatus* (Hancock, 1828)	Sailfin catfish
12.	*Pterygoplichthys pardalis* (Castelnau, 1855)	Amazon Sailfin catfish
13.	*Gambusia affinis* (Baird and Girard, 1853)	Mosquito fish
14.	*Gambusia holbrooki* (Girard, 1859)	Mosquito fish
15.	*Oncorhynchus mykiss* (Walbaum, 1792)	Rainbow trout
16.	*Salmo trutta* (Linnaeus, 1758)	Brown trout
17.	*Salvelinus fontinalis* (Mitchill, 1814)	American brook charr
18.	*Oreochromis mossambica* (Peters, 1852)	Mozambique tilapia
19.	*Oreochromis niloticus* (Linnaeus, 1758)	Nile tilapia
	Reptile	
1.	*Trachemys scripta* (Schoepff, 1792)	Yellow-bellied slider turtle Common Slider

20.8 Invasive Alien Species in Marine Ecosystem

The coastal and marine ecosystems of India are invaded by 98 species of invasive or exotic species of faunal communities, including 11 cnidarians, 3 ctenophores, 5 molluscs, 16 annelids, 26 arthropods, 6 bryozoans, 1 entoprocta, and 30 ascidians (Table 20.3).

20.9 Challenges

The freshwater ecosystems of the world are extensively threatened by the spread of invasive alien species (CBD 2001). Many evidences are available to interpret the extent of the damages on the local and native ecosystem due to the arrival of non-native species, which later on acted as invasive alien species (Gallardo et al. 2016; Magliozzi et al. 2020). The general impacts are described below. Invasive alien species are established with a greater rate of propagation, wide ranges of morphological variation, rapid and high rate of growth features, eco-friendly sustainability, superior and quick reproductive accomplishment, the unconventional capability of spreading, an extensive variety of feeding preferences, etc. which supports them for the successful establishment beyond its natural native population range through the process of as bioinvasion (Shenkar and Swalla 2011; Jaffarali et al. 2014). The establishment of the newly invaded invasive species generates extraordinary pressures on the native species population, especially resource partitioning like nutrients, light, physical space, water, or food. The race can be realized as fatal for the native species population, including the endemic population either by predation or alteration of community structure or by changing the genetic make-up through interbreed, the introduction of parasitic activities and pathogen-related issues, etc. (SCBD 2003; Ward and Ricciardi 2007; Aguin-Pombo et al. 2012; Gérard et al. 2014; Carlos-Júnior et al. 2015; Gallardo et al. 2016; Meira et al. 2019; Magliozzi et al. 2020). It is found that the invasion leads to changes in ecological parameters across the globe, used to develop emergency in biodiversity and conservational characteristics, damages the ecosystem for the maintenance of its natural traits, changes of trophic structure, food webs, and pyramids, followed by fragmentation, devastation, the shift of the entire ecosystem (McNeely et al. 2001; Mooney 2005; Charles and Dukes 2007; Herron et al. 2007, Pejchar and Mooney 2009). It is recorded that IAS is one of the major causes for the extinction of 261 species of animals and 39 species of plants across the globe (Pyšek et al. 2020). The generalized impacts of the invasive alien species are briefly summarized below.

Table 20.3 Marine exotic/invasive alien species of India

S. No.	Taxonomic group(s)/name	Common name	Nativity /range	Introduction/distribution in India	Remarks/References
	Phylum Cnidaria				
	Class Scyphozoa				
	Order Rhizostomeae				
	Family Mastigiidae				
1.	*Phyllorhiza punctata* (Lendenfeld 1884)	Australian spotted jellyfish	Australia and the Phillippines	Gulf of Mannar	Invasive worldwide; Proficient at invading new zones Saravanan et al. (2016), Fofonoff et al. (2017)
	Family Cepheidae				
2.	*Marivagia stellata* (Galil and Gershwin 2010)		Indian Ocean	Kerala	Invaded the Mediterranean Sea through the Suez Canal; Kerala Coast is established as its origin from Indian waters Galil et al. (2010, 2013)
	Order SemaeostomeaeAE Family Pelagiidae				
3.	*Pelagia noctiluca* (Forsskal 1775)	The Mauve stinger	Europe	Kerala, Tamil Nadu	Invasive throughout oceanic waters; negatively impacts aqua-culture; invasive in its native range; not common in coastal waters Kramp (1961), Ramakrishna and Sarkar (2003), Purcell (2005)
	Family Cassiopeidae				
4.	*Cassiopea andromeda* (Forsskal 1775)	Upside-down jellyfish	Indo west Pacific	East and West coast of India, Andaman Islands	Invasive worldwide; transferred through the Suez Canal to the Mediterranean Sea, the Aegean

					Sea, the Levantine Sea; no poisonous effect Rao (1931), Menon (1930, 1936), Kramp (1961), Ramakrishna and Sarkar (2003), Venkataraman et al. (2012), Prasade et al. (2016)
	Class Hydrozoa				
	Order Leptothecata Family Blackfordidae				
5.	*Blackfordia virginica* (Mayer 1910)	Black Sea jellyfish	Black Sea	Mumbai, Bassein Creek estuarine complex in India	Found in estuarine habitat in 13 countries; Argentina, Brazil, Bulgaria, China, France, India, Cuba, Canada, Mexico, Guatemala, Jamaica, Mexico, Portugal, Russia, South Africa, Spain, Ukraine, and the United States; fast and efficient nature of reproduction; transported by shipping vectors Santhakumari et al. (1997), Kimber (2014)
	Family Eirenidae				
6.	*Eugymnanthea* sp.			East Coast of India	Raju et al. (1974), Anil et al. (2002)
	Order Anthoathecata Family Tubulariidae (Goldfuss 1818)				
7.	*Ectopleura crocea* (Agassiz 1862)	Pink-mouth hydroid	The Atlantic coast of North America	The east and west coasts of India	Extended from Mission Bay, California to Alaska; introduced to Australia, New Zealand, Europe, the Mediterranean, the

(continued)

Table 20.3 (continued)

S. No.	Taxonomic group(s)/name	Common name	Nativity /range	Introduction/distribution in India	Remarks/References
					Azores, Madeira, and South Africa Mammen (1963), Gravely (1927), Nagale and Apte (2013), http://invasions.si.edu/nemesis/
	Family Bougainvilliidae (Lütken 1850)				
8.	*Bimeria vestita* (Wright 1859)		The Firth of Forth, Scotland	The east and west coasts of India	Distribution includes both the western and eastern sides of the Atlantic Ocean; the Mediterranean and Black Seas, the Indian Ocean, and the East Pacific from Mexico to Chile Annandale (1907), Mammen (1963), Fofonoff et al. (2017)
	(Soft Coral) Class Anthozoa (Ehrenberg 1834) Subclass Octocorallia (Haeckel 1866) (Lamouroux 1812) Family Clavulariidae (Hickson1894)				
9.	*Carijoa riisei* (Duchassaing and Michelotti 1860)	Snowflake coral	Western Atlantic Ocean, from South Carolina to Brazil	Andaman and Nicobar Islands, Gulf of Kachchh, Gulf of Mannar, Thiruvanathapuram, Kanyakumari, and Goa	Divya et al. (2012), Raghunathan et al. (2013), Padmakumar et al. (2011), Patro et al. (2015), Nandakumar (2016)
	(Sea anemone) Class Anthozoa (Ehrenberg 1834) Subclass Hexacorallia (Haeckel 1896)				

	Order Actiniaria (Hertwig 1882) Family Diadumenidae (Stephenson 1920)				
10.	*Diadumene lineata* (Verrill 1869)	Orange striped anemone	Japan, Hong Kong	West coast of India	Worldwide distribution Parulekar (1968), Saunders et al. (2013), Lin and Weir (2016), Fautin et al. (2009), Hancock et al. (2017)
	(Scleractinian coral) Class Anthozoa (Ehrenberg 1834) Subclass Hexacorallia (Haeckel 1896) Order Scleractinia Family Dendrophylliidae (Gray 1847)				
11.	*Tubastrea coccinea* (Lesson 1829)	Orange cup coral	Brazil, Caribbean Sea, Gulf of Guinea, Gulf of Mexico	Andaman and Nicobar Islands, Gulf of Mannar, Gulf of Kachchh, and Lakshadweep	Venkataraman (2006), Caerio (1999), Pillai and Patel (1988)
	Phylum Ctenophora				
	Class Nuda Order Beroida Family Beroidae				
12.	*Beroe ovata* (Bruguiere 1789)		Atlantic coasts of North and South America	West coast of India	Biological control over ctenophore species *Mnemiopsis* and *Pleurobrachia* Chopra (1960), Purcell and Arai (2001), Shiganova et al. (2014), Volovik and Korpakova (2004)
13.	*Beroe cucumis* (Fabricius 1780)	Pink slipper comb jelly	Atlantic waters	West coast of India	Predator of *Pleurobrachia* Robin et al. (2009), Shiganova et al. (2014)
	Class Tentacalata				

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Table 20.3 (continued)

S. No.	Taxonomic group(s)/name	Common name	Nativity /range	Introduction/distribution in India	Remarks/References
	Order Platyctenida Family Ctenoplanidae				
14.	*Vallicula multiformis* (Rankin 1956)		Jamaica	Gulf of Kachchh	Distribution includes Brazil, Bermuda, California, Madeira, the Canary Islands, Cuba, Hawaii, the Caribbean, Europe, and the southeast Atlantic Rankin (1951), Marcus (1957), Prasade et al. (2015)
	Phylum Mollusca				
	Class Gastropoda Order Nudibranchia Family Policeridae (Alder and Hancock 1845)				
15.	*Thecacera pennigera* (Montagu 1813)	Winged the camera	Atlantic coast of Europe	Kerala coast	By ballast waters; invasive to Australia, the Tasman Sea, the United States Nandakumar (2016) (www.thehindu.com)
	Class Bivalvia Order Mydia Family Dreissenidae (Gray 1840)				
16.	*Mytilopsis sallei* (Recluz 1849)	Caribbean false mussel	Atlantic waters	The east and west coasts of India	Ganapati et al. (1971), Karande and Menon (1975), Raju et al. (1988)
	Order Mydia Family Teredinidae (Rafinesque 1815)				

17.	*Lyrodus medilobatus* (Edmonson 1942)		Indo-Pacific, Hawaiian Island, New Zealand, Australia, Virginia, Bermuda	West coast of India	Santhakumaran (1986)
	Family Pholadidae (Lamarck 1809)				
18.	*Martesia striata* (Linnaeus 1758)	Striated wood paddock	Native range is unknown	The east and west coasts of India, Lakshdweep, Andaman and Nicobar Islands	Wood-boring; Worldwide distribution; occurs naturally in the Atlantic, Pacific, and Indian Oceans; invasive to England, Ireland, Pearl Harbour, Hawaii; dispersed passively or by ship or by drift wood Nair and Dharmaraj (1983), Surya Rao and Subba Rao (1991), Ravinesh and Biju Kumar (2015), Çevik et al. (2015), Nawrot et al. (2015)
	Order Mytilida Family Mytilidae (Rafinesque 1815)				
19.	*Perna* (Linnaeus 1758)	(Brown Mussel)	The Red Sea, the east coast of South Africa	West coast of India, Tamil Nadu	Introduced by ballast water to India from Oman region 100 years ago; Invasive to Mediterranean Sea, North America, Gulf of Mexico; it resembles the native species *Perna viridis* Kuriakose and Nair (1976), Mahapatro et al. (2015), Kesavan et al. (2009), Shanmugam and Vairamani (2009), Harkantra and Rodrigues (2004), Menon and Pillai (1996), www.thehindu.

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Table 20.3 (continued)

S. No.	Taxonomic group(s)/name	Common name	Nativity /range	Introduction/distribution in India	Remarks/References
					com/article16643556.ece, Nawrot et al. (2015)
	Phylum Annelida				
	Class Polychaeta Order Sabellida Family Serpulidae (Rafinesque 1815)				
20.	*Ficopomatus enigmaticus* (Fauvel 1923)	Australian Tube worm	Australia	Indian Ocean	
21.	*Protula tubularia* (Mon-tagu 1803)	Bristle worm	Native range is unknown	Mumbai	Gaonkar et al. (2010)
22.	*Hydroides elegans* (Haswell 1883)		Indo-Pacific	The east coast of India	Mahapatro et al. (2015)
	Order Phyllodocida Family Glyceridae (Grube 1850)				
23.	*Glycera longipinnis* (Grube 1878)		The Philippines	Mumbai, Andaman and Nicobar Islands	Gaonkar et al. (2010)
	Family Nereididae (Blainville 1818)				
24.	*Neanthes cricognatha* (Ehlers 1904)		New Zealand	Mumbai, Andaman and Nicobar Islands	Gaonkar et al. (2010)
25.	*Nereis falcaria* (Willey 1905)			Mumbai	Gaonkar et al. (2010)
26.	*Perinereis nuntia* (Lamarck 1818)		Gulf of Suez	Mumbai, Andaman and Nicobar Islands, Lakshadweep	Gaonkar et al. (2010)
	Order Terebellida Family Cirratulidae (Carus 1863)				

27.	*Protocirrineris chrysoderma* (Claparede 1868)			Mumbai, Lakshadweep	Gaonkar et al. (2010)
	Family Cossuridae (Day 1963)				
28.	*Cossura coasta* (Kitamori 1960)		Greece	Mumbai	Gaonkar et al. (2010)
	Family Maldanidae (Malmgren 1867)				
29.	*Petaloproctus terricolus* (Quatrefages 1866)		San Sebastian, South West Africa	Mumbai	Gaonkar et al. (2010)
	Order Eunicida Family Lumbrineridae (Schmarda 1861)				
30.	*Lumbrineris japonica* (Marenzeller 1879)		Japan	Mumbai	Gaonkar et al. (2010)
31.	*Lumbrineris bifilaris* (Ehlers 1901)		The Pacific Ocean	Mumbai	Gaonkar et al. (2010)
	Family Onuphidae Kinberg 1865				
32.	*Onuphis eremita* (Audouin & Milne Edwards 1833)		Atlantic Ocean,	Bay of Bengal, Mumbai	Gaonkar et al. (2010)
33.	*Onuphis holobranchiata* (Marenzeller 1879)		Japan	Mumbai	Gaonkar et al. 2010
	Order Spionida Family Spionidae (Grube 1850)				
34.	*Scolelepis squamata* (Muller 1806)		Gulf of Mexico and the Caribbean Sea	Mumbai, Andaman and Nicobar Islands	Gaonkar et al. (2010)
35.	*Malacoceros indicus* (Fauvel 1928)		Australia	Mumbai, Andaman and Nicobar Islands	Gaonkar et al. (2010)
	Phylum Arthropoda				

(continued)

Table 20.3 (continued)

S. No.	Taxonomic group(s)/name	Common name	Nativity /range	Introduction/distribution in India	Remarks/References
	Subphylum CrustaceaRUSTACEA Class Malacostraca Order Isopoda Family Cirolanidae (Dana 1852)				
36.	*Cilicaea lateraillei* (Leach 1818)		Indonesia, the Philippines, Sri Lanka, South Africa, the Red Sea, Australia	Arabian Sea	Venugopalan and Wagh (1987), Anil et al. (2002)
37.	*Cirolana harfordi* (Lockington 1877)			Indian waters	Anil et al. (2003) Exotic
	Family Sphaeromatidae (Latreille 1825)				
38.	*Paradella dianae* (Menzies 1962)		Pacific coasts of North and Central America	India	Anil et al. (2003), Roy and Nandi (2017) Exotic
39.	*Sphaeroma serratum* (Fabricius 1787)			India	Anil et al. (2003), Roy and Nandi (2017) Exotic
40.	*Synidotea laevidorsalis* (Miers 1881)		Australia, California	India	Anil et al. (2003), Roy and Nandi (2017) Exotic
	Order Amphipoda Family Stenothoidae (Boeck 1871)				
41.	*Stenothoe gallensis* (Walker 1904)		China, Sri Lanka	The east and west coasts of India	Walker (1904), Venugopalan and Wagh (1986), Anil et al. (2003) Exotic
42.	*Stenothoe valida* (Dana 1852)		Brazil, Australia	Indian waters	Shyamasudari (1997) Exotic
	Family Ischyroceridae (Stebbing 1899)				

43.	*Jassa falcata* (Montagu 1808)		Black sea, the British coast and the Ireland coast	Indian waters	Shyamasudari (1997) Exotic
44.	*Jassa marmorata* (Holmes 1905)		Native distribution is unknown; first described from Rhode Island, the North Atlantic	Indian waters	It is introduced to Western North America, South America, South Africa, Australia, New Zealand, China, Japan, and Russia; Exotic Anil et al. (2003), Fofonoff et al. (2017)
45.	*Ericthonius brasiliensis* (Dana 1853)		Atlantic Ocean at Rio de Janeiro	The east and west coasts of India	Venugopalan and Wagh (1986) Exotic
	Family Maeridae (Krapp-Schickel 2008)				
46.	*Quadrimaera pacifica* (Schellenberg 1938)		Australia, Madagascar, North Pacific Ocean, Panama, Republic of Mauritius	The east and west coasts of India	Venugopalan and Wagh (1986), Anil et al. (2002) Exotic
47.	*Elasmopus rapax* (Costa 1853)		Gulf of Califorinia	Indian waters	Shyamasudari (1997)
	Family Podoceridae (Leach 1814)				
48.	*Podocerus brasiliensis* (Dana 1853)		Atlantic Ocean at Rio de Janeiro and Brazil	The east and West coasts of India	Venugopalan and Wagh (1986), Shyamasudari (1997), Anil et al. (2003)
	Family Corophiidae (Leach 1814)				
49.	*Monocorophium acherusicum* (Costa 1853)		Europe	Indian waters	Shyamasudari (1997)
	Family Caprellidae (Leach 1814)				
50.	*Paracaprella pusilla* (Mayer 1890)		Brazil	Indian waters	Reported from many marinas on the Atlantic and Mediterranean coasts, Australia, Hawaii; Exotic Mayer (1890), Guerra-Garcia (2010), Alarcón-Ortega (2015)

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Table 20.3 (continued)

S. No.	Taxonomic group(s)/name	Common name	Nativity /range	Introduction/distribution in India	Remarks/References
	Order Decapoda Family Penaeidae (Rafinesque 1815)				
51.	*Penaeus vannamei* (Boone 1931)		Eastern Pacific coast	India	Wakida-Kusunoki et al. (2011) Worldwide distribution; Introduced for aquaculture purpose; Exotic
	Class Hexanauplia Infraclass Cirripedia Order Sessilia Family Balanidae (Leach 1806)				
52.	*Amphibalanus amphitrite* (Darwin 1854)		The West Pacific and Indian Oceans from Southeastern Africa to Southern China.	Mumbai, Andaman and Nicobar Islands	Invaded the Eastern Pacific (Panama-California), Northwestern Pacific (Korea-Japan-Russia), Southwestern Pacific (including New Zealand and Southern Australia), (Hawaii Islands), Western Atlantic (Caribbean-Long Island Sound), and Northeastern Atlantic (Germany-the UK-France) Bhatt and Bal (1960), Anil et al. (2003), Fofonoff et al. (2017)
53.	*Amphibalanus eburneus* (Gould 1841)			Indian waters	Invasive to the Northeast Atlantic, the Indian Ocean,

			The Western Atlantic from the southern Gulf of Maine to Venezuela		Northwestern and the Northeastern Pacific; compete with cultured oysters Anil et al. (2003), Fofonoff et al. (2017)
54.	*Fistulobalanus pallidus* (Darwin 1854) = *Balanus amphitrite* var. *stutsburi*		West coast of Africa	West coast of India	Anil et al. (2003) Exotic
55.	*Megabalanus tintinnabulum* (Linnaeus 1758)		The North Sea	Indian waters	Anil et al. (2003) Harmful species; Exotic
56.	*Megabalanus zebra* (Russell et al. 2003)		China	Indian waters	Anil et al. (2003)
	Class Hexanauplia Subclass Copepoda Order Calanoida Family Calanidae (Dana 1849)				
57.	*Nannocalanus minor* (Claus 1863)			Mumbai	Gaonkar et al. (2010)
58.	*Cosmocalanus* sp.			Mumbai	Gaonkar et al. (2010)
	Family Paracalanidae (Giesbrecht 1893)				
59.	*Paracalanus* sp.			Mumbai	Gaonkar et al. (2010)
	Family Tortanidae (Sars 1902)				
60.	*Tortanus* sp.			Mumbai	Gaonkar et al. (2010)
	Order Harpacticoida Family Tachidiidae (Sars 1909)				
61.	*Euterpina acutifrons* (Dana 1847)			Mumbai	Gaonkar et al. (2010)

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Table 20.3 (continued)

S. No.	Taxonomic group(s)/name	Common name	Nativity /range	Introduction/distribution in India	Remarks/References
	Phylum Bryozoa				
	Class Gymnolaemata Order Ctenostomatidae Family Vesiculariidae				
62.	*Amathia verticillata* (delle Chiaje 1822)		The Mediterranean Sea	Chennai, Vishakhapatnam, Cuddalore, Palk Bay, Colachal, and Mumbai	Distributed worldwide from the Mediterranean to tropical, sub-tropical environments within the Atlantic and Indo-Pacific Oceans Robertson (1921), Ganapathi and Satyanarayana Rao (1968), Nair et al. (1992), Swami and Udhayakumar (2010), Bhave and Apte (2012), Yedukondala Rao and RakeshSarma (2013), Pati et al. (2015), Prince Prakash Jebakumar et al. (2017), Fofonoff et al. (2017)
	Order Cheilostomatidae Family Bugulidae (Gray 1848)				
63.	*Bugula neritina* (Linnaeus 1758)		Mediterranean and American seas	The west and east coasts of India	Cosmopolitan; potential to be a fouling pest Robertson (1921), Menon (1967), Subba Rao and Sastry (2005), Ryland et al. (2011)

64.	*Bugulina stolonifera* (Ryland 1960)		Swansea, Wales; Northwest Atlantic	West coast of India	Extended from New Hampshire to the Gulf of Mexico, Bermuda, and Jamaica; introduced to the West Coast of the United States, Panama, Hawaii, Australia, New Zealand, China, India, Brazil, Argentina, and Europe Fofonoff et al. (2017)
65.	*Bugulina flabellata* (Thompson in Gray 1848)		The Northeast Atlantic, from southern Norway to Morocco and the Mediterranean Sea	East coast of India	Distribution includes Australia, New Zealand, India, Brazil, Argentina and Chile Menon (1967), Fofonoff et al. (2017)
	Family Cryptosulidae (Vigneaux 1949)				
66.	*Cryptosula pallasiana* (Moll 1803)		Atlantic, from Norway to Morocco, Mediterranean and Black Seas, Nova Scotia to Florida	West coast of India	The most competitive fouling organisms in ports Molnar et al. (2008), http://www.exoticsguide.org/images/c_pallasiana_lg_b.jpg
	Family Membraniporidae (Busk 1852)				
67.	*Membranipora membranacea* (Linnaeus1767)	Coffin box	Eastern Canada, Nova-Scotia	East coast of India	Resembles native bryozoan *Electra pilosa*; forms crust on algae; Proliferation in the Gulf of Maine has already destroyed entire kelp forests waves-vagues.dfo-mpo.gc.ca/Library/365586, Fofonoff et al. (2017)

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Table 20.3 (continued)

S. No.	Taxonomic group(s)/name	Common name	Nativity /range	Introduction/distribution in India	Remarks/References
	Phylum Entoprocta				
	Family Barentisiidae				
68.	*Barentsia ramosa* (Robertson 1900)		Pacific, California, Belgium	Indian Ocean	
	Phylum Chordata				
	(Ascidian) Class Ascidiacea Family Ascididae				
69.	*Ascidia sydneiensis* (Stimpson 1855)		Indo-Pacific and Atlantic ocean, Sub Antarctic region, East South America	Tuticorin port—Gulf of Mannar	Tamilselvi et al. (2011)
70.	*Ascidia gemmata* (Sluiter 1895)		Indo-West Pacific	Tuticorin port—Gulf of Mannar	Tamilselvi et al. (2011)
71.	*Phallusia nigra* (Savigny 1816)		Panama, USA, Indo-Pacific, Atlantic and the Mediterranean	Tuticorin port—Gulf of Mannar and Andaman and Nicobar Islands	Tamilselvi et al. (2011), Jhimli et al. (2015)
72.	*Phallusia arabica* (Savigny, 1816)		Indo West Pacific and North east Atlantic	Tuticorin port—Gulf of Mannar	Tamilselvi et al. (2011)
73.	*Phallusia polytrema* (Herdman 1906)		Indo-West Pacific Region, East South America, Pan tropical throughout the Caribbean	Tuticorin port—Gulf of Mannar	Tamilselvi et al. (2011)
	Family Pyuridae				
74.	*Herdmania pallida* (Savigny 1816)		Atlantic Ocean, Indo-West Pacific and the Mediterranean: Sub Antarctic region	Tuticorin port—Gulf of Mannar	Tamilselvi et al. (2011)
75.	*Microcosmus curvus* (Tokioka 1954)		Pacific ocean	Tuticorin port—Gulf of Mannar	Tamilselvi et al. (2011)

76.	*Microcosmus squamiger* (Michaelsen 1927)		Indo-Pacific, Southwest Atlantic and the Mediterranean Sea: Sub Antarctic region	Tuticorin port—Gulf of Mannar	Tamilselvi et al. (2011)
77.	*Microcosmus exasperates* (Heller 1878)		Indo-West Pacific, Atlantic Ocean and the Mediterranean: East Africa, SubAntarctic, southeast America	Tuticorin port—Gulf of Mannar	Tamilselvi et al. (2011), Jaffarali et al. (2015)
78.	*Herdmania momus* (Savigny 1816)		Mediterranean Sea. North Atlantic Ocean, Federal Republic of Somalia, Mozambique	South western coast of India	Jaffarali et al. (2015)
	Family Perophoridae				
79.	*Perophora formosana* (Oka 1931)		Indo-West Pacific and Atlantic Ocean	Tuticorin port—Gulf of Mannar	Tamilselvi et al. (2011)
80.	*Ecteinascidia garstangi* (Sluiter 1898)		Madagascar, South Pacific Ocean	South western coast of India	Jaffarali et al. (2015)
	Order Stolidobranchia Family Styelidae (Sluiter 1895)				
81.	*Eusynstyela tincta* (Van Name 1902)		Atlantic Ocean and Indo-West Pacific: East South America	Tuticorin port—Gulf of Mannar	Tamilselvi et al. (2011)
82.	*Styela canopus* (Savigny 1816)		Indo-Pacific, Atlantic Ocean, and the Mediterranean: South and South east America	Tuticorin port—Gulf of Mannar	Tamilselvi et al. (2011), Renganathan (1981)
83.	*Symplegma oceania* (Tokioka 1961)		Indo-West Pacific	Tuticorin port—Gulf of Mannar	Tamilselvi et al. (2011)
84.	*Symplegma viride* (Herdman 1886)		Atlantic Ocean, Indo-West Pacific and the Mediterranean: Sub Antarctic East South America	Tuticorin port—Gulf of Mannar	Tamilselvi et al. (2011)
85.	*Botryllus schlosseri* (Pallas 1766)		South Africa—Alexander Bay and Durban Bay	South-western coast of India and South-eastern coast of India—Tamil Nadu	Jaffarali et al. (2009, 2015)

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Table 20.3 (continued)

S. No.	Taxonomic group(s)/name	Common name	Nativity /range	Introduction/distribution in India	Remarks/References
86.	*Botrylloides magnicoecum* (Hartmeyer, 191)		Indo-West Pacific and Western Central Atlantic	Tuticorin port—Gulf of Mannar	Tamilselvi et al. (2011)
87.	*Botrylloides leachii* (Savigny 1816)		Northeast Atlantic, Indo-West Pacific and Mediterranean and Black seas, Australia, and Europe	Tuticorin port—Gulf of Mannar	Tamilselvi et al. (2011), Jaffarali et al. (2015)
88.	*Botgrylloides chevalense* (Herdman 1906)		Eastern Indian Ocean: India	Tuticorin port—Gulf of Mannar	Tamilselvi et al. (2011)
	Family Didemnidae				
89.	*Didemnum psammatodes* (Sluiter1895)		Indo-West Pacific and Eastern Atlantic; Subantarctic region, Malaya, and West Africa	Tuticorin port—Gulf of Mannar	Tamilselvi et al. (2011)
90.	*Didemnum candidum* (Savigny 1816)		North Pacific Ocean	South eastern coast of India—Tamil Nadu	Jaffarali et al. (2009)
91.	*Didemnum fragile* (Sluiter 1909)		Australia	South western coast of India	Jaffarali et al. (2015)
92.	*Lissoclinum fragile* (Van Name 1902)		Indo-Pacific and Western central Atlantic	Tuticorin port—Gulf of Mannar	Tamilselvi et al. (2011)
93.	*Diplosoma listerianum* (Milne-Edwards 1841)		South Africa—Alexander Bay, Durban Bay, Lange Baan Bay	South-western coast of India	Jaffarali et al. (2015)
94.	*Trididemnum clinides* (Kott 1977)		Indo-West Pacific	Tuticorin port—Gulf of Mannar	Tamilselvi et al. (2011)
95.	*Trididemnum savignii* (Herdman 1886)		Indo-Pacific and Western Central Atlantic	Tuticorin port—Gulf of Mannar	Tamilselvi et al. (2011)
	Family Polycitoridae				

96.	*Eudistoma viride* (Tokioka 1955)		Western Central Pacific and Indian Ocean	Tuticorin port—Gulf of Mannar	Tamilselvi et al. (2011)
97.	*Aplidium multiplicatum* (Sluiter 1909)		Indo-West Pacific	Tuticorin port—Gulf of Mannar	Tamilselvi et al. (2011)
98.	*Polyclinum glabrum* (Sluiter 1895)		Central Indo-Pacific	South-western coast of India	Jaffarali et al. (2015)

20.9.1 Damage in Coastal Structure

The coastal structures of the world are being protected with the presence of a variety of biogenic habitats like coral reefs, seagrass beds, oysters, as well as mussel reefs, kelp forests, etc. (Boström et al. 2011; Salomidi et al. 2012; Liquete et al. 2013; Katsanevakis et al. 2014). These structures are extensively important for coastal protection by means of providing several services, especially physical services. The successful establishment of IAS makes extensive threats to the coastal ecosystem of native species and destroys the stability of the coastal zones by killing the faunal communities of the above-said ecosystems.

20.9.2 Food Production and Economy

The aquatic environment is one of the best areas of resource providers in the form of food which is also directly related to economic development. Fish and fisheries as well as aquaculture aspects are the major areas of food production along with commercial activities, which may face greater ranges of negative impact due to the spread of invasive alien species. Fisheries and aquaculture are completely dependent on planktonic occurrence and abundance (Katsanevakis et al. 2014). The blooming of invasive phytoplankton can damage the fisheries as well as aquaculture of any region, which is detrimental for food production and health issues and economic balance as well (Nehring 1998). Invasive parasitic species make serious damage to the fishe and resulted in mortality (Raine et al. 2001). Some invasive alien species of algae create severe impairment to the entire aquatic ecosystem and contribute to a substantial negative impact. Invasive species of fishes are directly damaging the native species population as well as the aquatic ecosystem by predation (Zolotarev 1996; Sahin et al. 2009; Salomidi et al. 2012; Katsanevakis et al. 2014). Some IAS are acting as hosts and carriers of several diseases and take an active part in the transmission of disease in the aquatic ecosystem, which can result in a greater range of mortality among the species related to fisheries and aquaculture (Payen and Bonami 1979; Stebbing et al. 2012). The impact is considerably high for the native species population.

20.9.3 Tourism and Economy

The aquatic ecosystem is one of the potential areas of development for the purpose of tourism across the globe, especially the marine habitats are providing enormous scope for an excellent infrastructural organization for tourism activities. The successful establishment of tourism improves the economic aspects of the coastal population along with social development. The spread of IAS directly disturbs the economic growth of the coastal population with the reduction of tourism by damaging the natural environment.

20.9.4 Reduction of Water Quality

The aquatic ecosystem of the world is one of the dynamic environments which are being managed, cycled, and nourished by natural processes for its sustainability and supporting lives. Purification is an essential process to keep the water bodies fresh and alive. Some species of algae, seagrasses, molluscs, etc. are known to take a decisive role in the said process (Zolotarev 1996; Sala et al. 2011; Salomidi et al. 2012; Katsanevakis et al. 2014). The spread and occurrence of invasive species make a significant problem for the native species and restrict the process of water purification, followed by increased toxicity in the aquatic ecosystem (Streftaris and Zenetos 2006).

20.9.5 Reduction of Biofuels and Biotic Materials

The aquatic ecosystems are the potential source for the generation and development of biotic communities which substantially produce biotic material as well as are the noteworthy foundation for providing biofuels, especially from algal beds and seagrass meadows (Salomidi et al. 2012). The introduction and rapid proliferation of invasive alien species extensively damage those habitats. It is also important to note that some species of alien species are known to provide useful biotic materials and source for several medicinal as well as cosmetic industries (Katsanevakis et al. 2014).

20.9.6 Storage of Water

Invasive alien species are known to reproduce at a rapid rate, which makes their spread vigorous. The intensive growth of algae makes serious blooming to the entire water body, which is causing severe damage to the entire ecosystem, followed by faunal communities of the environment and human health. Some invasive alien species of bivalves, polychaetes, crustaceans, cnidarians, etc. are known as causative agents against the storage of waters (Katsanevakis et al. 2014).

20.9.7 Negative Impact on Carbon Sequestration

Aquatic ecosystems is one of the best environments for carbon sink or sequestration. Carbon dioxide is transformed into carbonic acid by reacting with water. This is the important source of carbonate for the formation of calcium carbonate for the animals with calcareous skeletal like corals and shelled animals like molluscs and some algae enriched with calcium to strengthen themselves against grazers. The presence of invasive alien species makes rapid reproduction and proliferation and results in the growth of the population on a massive scale, which profusely intakes most of the calcium carbonate from the source medium and creates a scarcity of calcium carbonate for the native species population. As a result, the growth of the reef habitat is disturbed, the hindrance being the growth and development of molluscs as well as algae. The shells of the molluscs can be seen as fragile and susceptible under minimum alteration of physiological as well as biochemical states and resulting in the decline of population density in a massive scale. The IAS slowly damages the carbon sink capacity of the aquatic habitats by damaging the seagrass ecosystem, algal beds, and even the mangrove ecosystem (Katsanevakis et al. 2014).

20.9.8 Negative Impact on Nutrient Content

The nutrient level in aquatic ecosystems is found in every stratum of the water column. The presence of algal bloom of IAS mostly destroys the nutrient level of water by consuming vigorously and creates an adverse impact on the nutrient content and also makes them unavailable for other native species (Littler 1980; Littler and Littler 1980; Wallentinus 1984; Schoemann et al. 2005; Katsanevakis et al. 2014).

20.9.9 Reduction of Air Quality

The evidence related to the reduction of the air quality due to the spread of IAS in aquatic ecosystems is not much documented across the world. A blooming event due to the presence of phytoplankton creates an immense negative impact in the aquatic habitat by generating anoxia as a result of the death of floral and faunal communities can be seen followed by the smell from those dead organisms. The generation of bad smells due to the decomposing bodies has a negative impact on the air quality (Leppäkoski 1991; Katsanevakis et al. 2014).

20.10 Preventing Measures

Owing to the fact of long-lasting and wide-ranging damaging impact on the various ecosystems along with making a substantial destructive impact on its services followed by the economic discrepancy, several agreements were made by considering the IAS as a global and rational threat (Magliozzi et al. 2020). Some international initiatives were already considered for the protection of native aquatic species from invasive species by Convention on Trade in Endangered Species (CITES) (1975), International Health Regulations (1982), Convention on Biological Diversity (1992), Law of the Sea Convention (1994), International Credential Evaluation Service (ICES) Code of Practice on the Introductions and Transfer of marine organisms (1994), WTO Agreement on Application of Sanitary and Phytosanitary Measures (1995), FAO Code of Conduct for Responsible Fisheries (1995), Convention on the Law of the Non-Navigational Uses of Watercourses (1997), International Maritime Organization Resolution A.868 (20) 1997, Guidelines for the control and Management of Ships Ballast Water to minimize the transfer of Harmful Aquatic Organisms and Pathogens through the GloBallast Program, IUCN Guidelines for the Prevention of Biodiversity Loss Caused by Alien Species (2000) (Bax et al. 2003).

20.10.1 Role of CBD

The need and urgency through the prompt action against the invasive species were well considered by the Convention on Biological Biodiversity (CBD) a long time before, especially hazard to the biomes, native species population shift, decline, and species extinction as well. These species are required to be protected with the help of preventive care by the introduction of mitigation measures (CBD 2000; Katsanevakis et al. 2014). The CBD made the long-term objectives of the Aichi Biodiversity 2020 for the management of IAS. In Target 9, it was defined that "*by 2020, invasive alien species and pathways are identified and prioritized, priority species are controlled or eradicated, and measures are in place to manage pathways to prevent their introduction and establishment*" (CBD 2000; Katsanevakis et al. 2014). The EU Biodiversity Strategy has also considered this as a fundamental issue for the biodiversity loss across Europe, while the Marine Strategy Framework Directive identifies plenty of hazardous matter on the native species population due to the arrival of invasive alien species (EU 2008, 2011; Katsanevakis et al. 2014). A new regulation was proclaimed by the European Union (28 countries) to safeguard biodiversity against the IAS with the aim to "*prevent the introduction of, control or eradicate alien species which threaten ecosystems, habitats or species*" in 2014 (Caffrey et al. 2015). In 2014, CBD provided a Strategic Plan for Biodiversity (2011–2020) among the parties related to the IAS. The action included the identification and prioritization of alien species trails and implementation of prompt actions to manage the routes to stop alien species introduction and establishment (Pyšek et al. 2020).

20.10.2 Indian Initiatives

Several wide-ranging initiatives are already taken in the Indian context against IAS along with national legislation such as:

1. The Prevention and Control of Infectious and Contagious Disease in Animals Act, 2009.
2. The Plant Quarantine (Regulation of Import into India) Order, 2003.
3. The Destructive Insects and Pests Act, 1914, and amendments.
4. The Plants, Fruits & Seeds (Regulation of Import into India) Order 1989 (PFS Order 1989).
5. Livestock Importation Act, 1898 and the Livestock Importation (Amendment) Ordinance, 2001.
6. Environment Protection Act, 1986.
7. The Biological Diversity Act, 2002.
8. Indian Forest Act, 1927.
9. Wildlife (Protection) Act, 1972.
10. Forest (Conservation) Act, 1980.

Besides, some international cooperation and agreements were developed as framework to control the introduction and spread of IAS. India is one of the signatories and active parties in the Asia-Pacific Forest Invasive Species Network (APFISN) of the FAO among the 32 member countries. The network was established to evaluate and control the IAS species and sustainable management of forests in the Asia-Pacific region. It also defines the information on exchange and benefit-sharing of FIS and sharing of technical expertise, including research, training, and education. It also denotes capacity-building programmes and the development of strategic cooperation to combat IAS. Indian Council of Agricultural Research and U.S. Department of Agriculture (USDA) made a joint declaration on knowledge sharing in the agricultural field.

20.11 Mitigations

Documentation and inventorying of native species of fauna and flora is a prerequisite to distinguishing the native species from invasive species. Since ballast water is one of the major sources of introduction of non-native species, strict compliance with International Maritime Organization (IMO) guidelines is to be followed for disposal in mid-sea. Identification of vectors for invasive species introduction is to be elucidated from time to time, while genetic control measures are to be found to minimize the propagation of invasive species in the non-native range. Regular inspection of the hull of ships can prevent the species' spread and transmission, especially of fouling organisms. Regulation of trade of exotic fauna and flora and also encouraging research funding for the prevention of invasive species using mechanical and biological measures. Further, international and national collaboration, and public awareness on the impact of the introduction of non-native species will be helpful to control the establishment and spread of the invasive alien species.

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Chapter 21
Reasons of Biodiversity Loss in India

Padma Sharma and Daizy R. Batish

21.1 Introduction

Biodiversity is the most astonishing aspect of life on earth and without it, the future of mankind looks rather bleak. People obtain various resources like food, medicine, clothing, and shelter from nature. With the increasing population, an increase in desire and demand for these resources arose. People gathered more and more natural products from the environment, impacting biodiversity in direct and indirect ways. With modernization, people switched to unsustainable agricultural and industrial practices for reaping more benefits. Since then, biodiversity started facing a constant fall, and the extinction of species through human activities grew at an alarming rate (UN report 2019). In developing economies like India, there are many reasons for the loss of biodiversity, which include a high rate of human population growth, technology-induced effects, unsustainable economic activities, and inadequate awareness of biodiversity values (Crist et al. 2017).

Conservation and preservation of global biodiversity have become one of the most critical environmental issues. Over time, it is estimated that the addition of new species and their identification increased to 8.7 million (globally), both on land as well as in the ocean (Mora et al. 2011). There is barely any area in this world that is not facing ecological changes. To some extent, biological extinction is a natural phenomenon, and it can happen due to evolutionary trends or various environmental factors such as earthquakes, floods, cyclones, avalanches, tsunami, wildfires, volcanos, etc. (Crist et al. 2017). The disappearance of species from the earth is occurring since the beginning of life; however, the population explosion and human intervention have accelerated these rates to a large extent. It is due to the changes in habitats

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and uncertainty in reproductive success that can eventually result in more deaths than births in a species. Habitat destruction, poaching, the introduction of invasive species, pollution, industrialization, agricultural practices, changing wetlands and forests to croplands, and urban sprawling have become the prominent causes of extinction by humans. The most well-known species driven to extinction is *Raphus cucullatus* (dodo), a flightless bird, endemic, and native of Mauritius. *Ectopistes migratorius* (passenger pigeons) is another such example from North America. In India, during the past few centuries, four animal species, such as the cheetah (*Acinonyx jubatus*), the sumatran rhinoceros (*Dicerorhinus sumatrensisi*), the pink-headed duck (*Rhodonessa caryophyllacea*), and the Himalayan quail (*Ophrysia superciliosa*), and 18 floral species have gone extinct, according to wildlife survey organization (The Hindu Report 2019). *Lastreopsis wattii*, a fern discovered in Manipur, three species from the genus *Ophiorrhiza* (*Ophiorrhiza brunonis*, *Ophiorrhiza caudata,* and *Ophiorrhiza radicans*) discovered from peninsular India, and *Corypha taliera*, a palm species discovered in Myanmar and the Bengal region have also become extinct (The Hindu Report 2019).

India is the seventh largest country in the world followed by Russia, Canada, the USA, China, Brazil, and Australia. According to the World Conservation Monitoring Centre (WCMC) of the United Nations Environment Program, India has been identified as one of the 17 megadiverse countries of the world. Approximately 2.4% of the total geographical area of India (surveyed by the Ministry of Environment and Forests) accounts for 7-8% of the recorded species of the world and includes over 45,000 plant species (including fungi and lower plants) and 91,000 animal species (MoEF 2009, 2014). According to the Botanical Survey of India (BSI) and Zoological Survey of India (ZSI), India represents 11.5% and 6.49% of the world's flora and fauna, respectively.

Environment protection has been institutionalized in the Constitution of India in the 42nd amendment of Article 48A, which is the part of Directive Principles of the State, and Article 51A (g), part of Fundamental Duties. Article 48A states "*The state shall endeavour to protect and improve the environment and safeguard the forests and wildlife*" and Article 51A (g) states, "*It shall be the duty of every citizen of India to protect and improve the natural environment including forests, lakes, rivers, and wildlife, and to have compassion for living creatures*." The government of India has also initiated a myriad of in-situ and ex-situ conservation practices. So, protected areas became the backbone of biodiversity conservation and nearly 4.74% of the total geographical area of India is under in situ conservation (NBAP 2008).

Since the Stockholm Conference on Human Environment and Development 1972, India has joined all the major international events related to environmental issues. India has participated and ratified many multilateral agreements related to environmental issues, including the Convention on Biological Diversity (CBD), 1992. In the year 2002, India also enacted the Biological Diversity Act (i.e. Biodiversity Act, 2002), which was initiated way back in 1994. With time, India formulated and implemented National Biodiversity Action Plan (NBAP) to act on threats as well as challenges of biodiversity conservation.

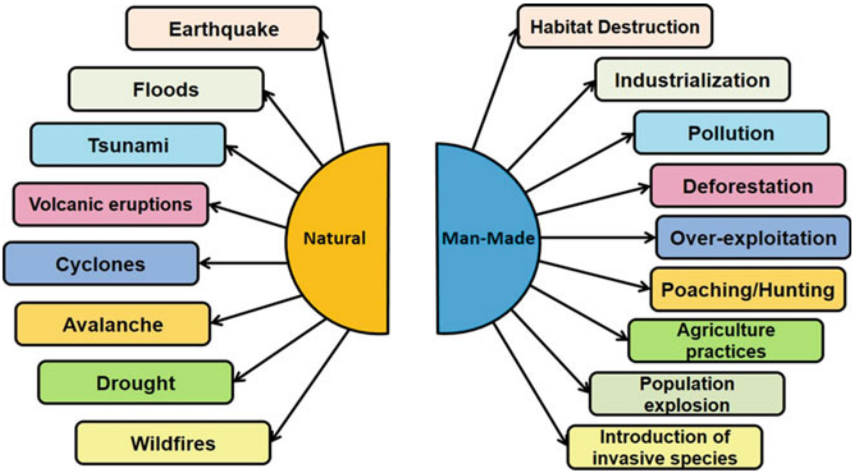

Fig. 21.1 Causes of biodiversity loss

In this chapter, we discuss major challenges of biodiversity change, i.e. biodiversity alterations (genetic diversity) and biodiversity loss (habitat disturbances, species abundances, and species distributions) (Fig. 21.1). The direct pressures on biodiversity impacts that modern humans and their ancestors have had on biodiversity and the recent change in biodiversity will be discussed.

21.2 Reasons for Loss of Biodiversity in India

21.2.1 Habitat Destruction

In the present time, habitat destruction has become the main threat to biodiversity. Over a billion people, both in urban as well as in rural areas, are residing in India. Their basic needs for survival such as food, fuel, shelter, and water has increased the pressure on the natural resources. The loss and fragmentation of habitat has resulted in increased man–animal conflicts, typically in the case of wild animals. Forests, meadows, and pastures that act as buffer zones between wildlife and human habitats have been gradually converted into agricultural fields and industries has resulted in habitat fragmentation. Habitat fragmentation and overexploitation declines the population of various plants and animals leading to their extinction, e.g. the Indian cheetah. Habitat cover of the Lion-tailed Macaque in the Western Ghats and the Great Indian Bustard in Madhya Pradesh, Gujarat, and Rajasthan, is also declining due to dwindling forests and fragmentation. It has also led to the depletion of genetic diversity of wild and cultivated plants, increased susceptibility to diseases, and lowered resistance to environmental changes. There are several reasons for which natural habitats are being destroyed by humans such as mining, highway and housing construction, building dams and industries, etc. Globally, 91% of plants, 89% of birds, and 83% of mammals are threatened because of habitat destruction (Hilton-Taylor 2000). According to International Union for Conservation of Nature (IUCN), most of the threatened avian species have been recorded from Indonesia (115), followed by Brazil (113), Colombia (78), China (76), Peru (75), and India (75) (Hilton-Taylor 2000). In India, the Western Ghats are known for rare and endemic butterfly species, and 70 out of 370 species are at risk of extinction due to habitat destruction (Thatheyus 2006). Continuous degradation and loss of habitat over the past few years have severely limited the availability and survivability of species (Menon and Bawa 1998). Thus, we need to not only avoid any further habitat destruction right away but also promote and restore a substantial fraction of the wilderness that has vanished in the past decades.

21.2.2 Hunting and Poaching

The evolutionary path of modern societies has originated from prehistoric societies of hunters and gatherers (Svizzero and Tisdell 2014). Earlier, people used to collect medicine and food from nature in a sustainable way, but with the increase in population, the scenario has changed. At present, wild animals are hunted for obtaining commercial products like skin, tusk, horn, medicines, decorative items, perfumes, and bones. Mostly large mammals such as elephants, lions, rhinoceros, tigers, etc. are facing pressure due to rampant hunting and poaching. In India, bones and skin from tigers, horns from rhinos, tusk from elephants, and the perfume from the musk deer are extensively marketed (Kirkpatrick and Emerton 2010). The overexploitation of Changthangi goat of Ladakh for the collection of wool called pashmina has led to the instances of inbreeding and consequently decline in its population. Similarly, crocodiles and gharial are hunted for their skin, and golden jackals for fur trade in Kashmir (Ganai et al. 2011). Because of increasing demand of pharmaceutical industries, poaching of the wild animals has increased, e.g. the poaching of tigers for their bones. Poachers also target other animals like squirrels, pheasants, bears, hornbills, ungulates, primates, etc. for numerous reasons (Ghosh-Harihar et al. 2019). Some of the examples of species affected by practices of hunting and poaching are listed in Table 21.1.

21.2.3 Over-Exploitation of Resources

India is a land of rich and diverse forests, ranging from tropical wet evergreen forests in the North-East to the tropical thorn forests in Central and Western India. There are ten biogeographic zones in India: Trans-Himalayas, Himalayas, Desert, Semi-arid, Western Ghats, Deccan peninsula, Gangetic plains, Coasts, Northeast India, and Islands. Based on climatic factors, forests are classified into 16 types and further

Table 21.1 Some species affected by practices of hunting and poaching

S. No.	Species	Part used	Purpose	References
1	Elephant (*Elephas maximus indicus*)	Tusk and ivory	Decoration purpose, billiard balls, manufacture of piano, dagger handle and mirror for decorations, bangles, furniture, medicine use, etc.	Anonymous (2003), Edwards (2001)
2	Changthangi goat (*Capra aegagrus hircus*)	Wool (pashmina)	Weaving shawl and coats	Ganai et al. (2011)
3	Kashmiri musk deer (*Moschus cupreus*), Alpine musk deer (*Moschus chrysogaster*), Himalayan musk deer (*Moschus leucogaster*), Black musk deer (*Moschus fuscus*) and Forest musk deer (*Moschus berezovskii*)	Caudal glands of male musk dear, skin	Perfume, musk pod and meat, medicine	Ilyas (2015)
4	One horned rhinoceros (*Rhinoceros unicornis*)	Horn and skin	Decorations and medicine	Sinha et al. (2011)
5	Tiger (*Panthera tigris tigris*)	Skin, bones, meat, claws and teeth, live specimens for zoo	Status symbols, decorations, medicine, luxury food, wine, jewellery, and décor items	Kirkpatrick and Emerton (2010), van Uhm (2016)

divided into 202 subgroups based on temperature, soil type, and plant species composition (MoEF 2014; FSI n.d.). There are a huge number of endemic and native plant species in the forests of this country. With time, the forests are facing threats due to their conversion into agricultural lands, industries, human settlements, and other developmental projects. Local demands for resources are rising far above the supportable and sustainable level. Construction of roads, railway tracks, artificial canals, shifting cultivation, and encroachments are the major threats. Excessive dependence on forest products, fodder, timber, fuelwood, overgrazing, and forest fires have been destroying these forests. As a result, some of the floral and faunal components, including many keystones and endemic forest species, are now left with a narrow population size that needs to be urgently conserved. Roughly 78% of the forest area is subjected to extensive grazing (FSI 1995) and around 36% are prone to forest fires (ISFR 2021). Indian herbal industries are entirely dependent on medicinal plants from the wild, and about 90% of medicinal plants are being harvested and traded from the wild zones. Therefore, the rich diversity of medicinal plants (approximately 6500 species) needs conservation on a priority basis in India (NBAP 2008). Some of the examples of over-exploited species of India are listed in Table 21.2.

Table 21.2 Some of the examples of over-exploited species of India

S. no.	Species	Habitat	Ecological status	Part used	Purpose	References
1	*Abies pindrow*	Himalayas	Endangered	Leaves	Antiulcerogenic, antimicrobial, anti-inflammatory, antihypertensive, antitussive, and CNS (central nervous system) activities	Samejo et al. (2010)
2	*Aconitum ferox*	Himalayas	Rare	Leaf, rhizomes, tuber, dried material	Antipyretic, analgesic, tonsillitis, sore throat, gastritis and debility	Shyaula (2011)
3	*Taxus baccata*	Himalayas	Endangered	Leaves, fruit, bark	Cytotoxic (anti-cancer cells)	Lanker et al. (2010)
4	*Colchicum luteum*	Himalayas	Vulnerable	Whole plant	Treatment of gout, rheumatism, cure liver and spleen disease and also purify blood	Ahmad et al. (2006)
5	*Magnolia griffithii*	Himalayas	Vulnerable	Stem	Timber used for poles, planks in house building	Chaudhry and Murtem (2017)
6	*Nepenthes khasiana*	Khasi Hills	Endangered	Whole plant	Medicinal purposes (night blindness, urinary troubles, cataract, skin diseases, diabetes, vaginal tumours, cysts and leprosy)	Joshi et al. (2021)
7	*Elaeocarpus ganitrus*	Tarai, Shiwaliks and middle Himalayas, foothills of the Himalayas	Endangered	Seed, fruit, leaves	Convulsions, cephalalgia, allergies, neurological diseases, asthma, diabetes, cancer, stress and many other blood circulatory disorders.	Singh et al. (2015)
8	*Rhododendron dalhousiae*	Western Ghats	Endangered	Leaves	Leaves are used as insect repellent	Paul et al. (2010)

9	*Juniperus communis*	Western Himalaya	Endangered	Branches and needles	Anti-mycobacterial activity	Carpenter et al. (2012)
10	*Betula utilis*	Himalayas	Critically endangered	Bark	Rheumatism, antiviral, gout, malaria	Singh et al. (2020)
11	*Ginkgo biloba*	Himalayas	Critically endangered	Seeds, leaves	Medicinal purpose	Paul et al. (2020)
12	*Rauwolfia serpentina*	Western Ghats	Critically endangered	Leaves, stem, flower	Hypertension, treat high blood pressure	Hazarika et al. (2019)
13	*Santalum album*	Western Ghats	Endangered	Whole plant	Oil, perfumes, medicines, cosmetic products	Nautiyal (2019)

21.2.4 Introduction of Invasive Species

Not only animals but plants also invade the area of native species. It has been proven that invasive alien species have become a significant driving force that alter any ecosystem and their services. Probability of invasion increases due to agricultural activities, globalization, climate change, and other anthropogenic activities (Rai and Singh 2020). Upon invasion, native species are subjected to competition for food and space (Custer and van Diepen 2020). Invasive alien species pose threat to biodiversity both globally as well as locally. For instance, the introduction of rabbits and goats in Indian and the Pacific regions has destroyed the habitats of several plants, birds, and reptiles (Chandrakar 2012). The most threatening invasive alien plant species in India include *Parthenium hysterophorus, Lantana camara, Ageratum conyzoides, Taraxacum officinale, Ageratina adenophora, Prosopis juliflora*, etc. (Bhatt et al. 2012). *Lantana* and *Parthenium* are recognized as the major contributors to economic loss and alteration of crop yield across India. *Chromolaena odorata* and *Mikania micrantha* are weeds and both are highly invasive in North-East Himalayan region and the Western Ghats. Wetlands and its biodiversity are also facing over-exploitation of aquatic resources, habitat destruction, water pollution, tourism, and the introduction of invasive alien species along with alien pathogens, pests, and parasites. Some of the introduced alien aquatic species like *Eichhornia crassipes, Pistia stratiotes, Salvinia molesta, Oreochromis niloticus, Clarias gariepinus, Cyprinus carpio* and *Pangasiandon hypophthalmus* have severely affected the aquatic ecosystems (www.nbaindia.org/cebpol). Some invasive species, other than plants, reported from India are listed in Table 21.3.

Forest Departments of various states along with NGOs and local communities have been managing the spread of invasive species through their utilization by making furniture and artifacts (e.g. *Lantana*) along with other methods of control, and, most importantly, by conducting awareness programs among the local people (NBAP 2008).

21.2.5 Deforestation

Land-cover changes in grasslands, forests, and mountains are also becoming a serious concern for the loss of biodiversity and hindering the proper functioning of an ecosystem (Kanade and John 2018). Deforestation, forest fires, and forest fragmentation (break up of a continuous landscape into small patches) may negatively influence the indigenous biodiversity (Fig. 21.2). The fundamental reasons behind deforestation are shifting cultivation, developmental projects (i.e. construction of roads and dams), population settlement, and their demands for fuelwood, food, raw materials for industries like pulp, paper, timber, plywood, furniture, etc. (Ahmad and Goparaju 2017). Loss and destruction of grasslands across the country have affected those populations which are dependent on grasslands like the bustard family (Great

Table 21.3 Some of the invasive species found in India

S. No.	Invasive species	Examples	Source of introduction (India)	References
1	Algae (fresh water and marine water)	*Kappaphycus, Microcystis, Caulerpa, Cladophora*	Unknown	MoEF (2014)
2	Coral	*Carijoa riisei*	Unknown	MoEF (2014)
3	Algae	*Acanthonyx euryseroche*	Ballast water	MoEF (2014)
4	Fish	Mosquitofish (*Gambusia affinis*)	Biological control	MoEF (2014)
5	Fish	Brown trout (*Salmo trutto*) and Rainbow trout (*Oncorhynchus mykiss*)	Recreational as well as consumption purposes	MoEF (2014)
6	Fish	African catfish (*Clarias gariepinus*)	Unknown	MoEF (2014)
7	Fish	Common carp (*Cyprinus carpio*) and Mozambique tilapia (*Oreochromis mossambicus*)	Aquaculture	MoEF (2014)

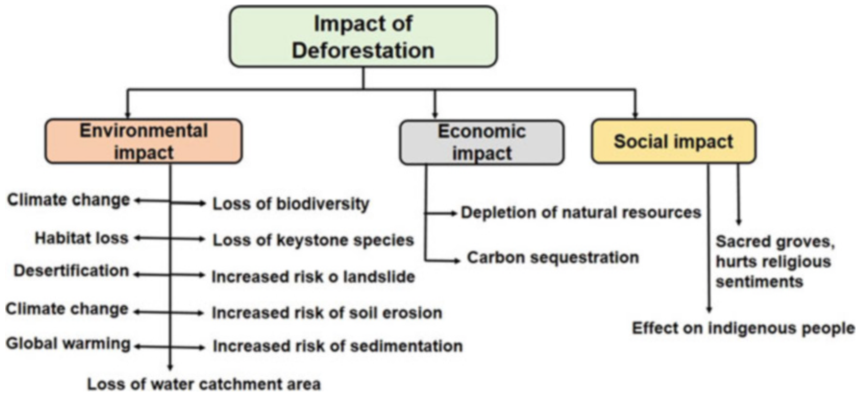

Fig. 21.2 Impact of deforestation on native flora

Indian bustard, Houbara bustard, etc.). In India, annually, approximately 13,000 km^2 of forest area has been cleared up and it is assumed that if deforestation goes on at this pace, the global loss of biodiversity from deforestation alone would be responsible for the extinction of 100 species every day (Chandrakar 2012).

21.2.6 Pollution and Climate Change

Pollution, whether it be soil, water, or air, alters the natural habitat. Plastics, chemicals (pesticides, insecticides, fungicides, etc.), and wastewater from industries become injurious to all living creatures on earth. Toxic chemicals released into the water bodies hamper the food chain, food web and affect the aquatic ecosystems. Gases like sulphur dioxide and nitrogen oxides (acid rain), carbon dioxide (global warming), and chlorofluorocarbons (ozone depletion) affect plants and animals locally as well as globally. According to the various studies, marine traffic is increasing at a very rapid rate, which includes watercraft ranging from small, motorized boats to large ships. Watercraft noise has posed a huge challenge to marine mammals, such as bottlenose dolphin (*Tursiops truncatus*), humpback whale (*Megaptera novaeangliae*), and beluga whale (*Delphinapterus leucas*). A study revealed significant changes in the physical and acoustic behaviour, masking of communication, and echolocation sounds and stress in marine animals (Erbe et al. 2019). Intergovernmental Panel on Climate Change (IPCC) noticed that environmental variables such as temperature, moisture content, and atmospheric gases such as nitrogen and carbon deposition were changing owing to climate change and global warming (IPCC 2014). By virtue of climate change, an upward shift of tree lines, as well as fauna, has been recorded. This would result in an increase in insect pests, parasites, and pathogens, coupled with a surge in plant and animal mortality (IPCC 2014). Over the past several decades, the coral reefs have been radically damaged. Coral reefs are threatened by water discharged from various industries, oil transport, offshore mining, and the agricultural sector (Maragos et al. 1996). Water pollution, over-exploitation of aquatic resources, oil spillage, garbage dumping, and chemical (pesticide and fungicide) waste from agricultural and industrial sectors are some of the main reasons for biodiversity loss. In addition to that, increased sea temperature and ocean acidification result in coral bleaching, which increases the coral mortality rate and reduces coral diversity. Bioinvasion is also an emerging threat to the native coral reef diversity, e.g. *Kappaphycus alvarezii* causes strong detrimental impacts on the reef diversity (De et al. 2017).

21.2.7 Other Reasons

There are some other factors which induce the loss of biodiversity such as narrow range distribution of a particular species and position of an organism in the food chain, i.e., the higher the position of a species, the more prone it is to extinction. Some large organisms tend to produce few offsprings after a long interval, which also results in reduced gene flow, and consequently the process of natural selection (i.e. evolution) may replace them with other species, leading to biodiversity loss (Chandrakar 2012).

21.3 Conclusions

Biodiversity loss is a major cause of concern in developing countries like India. The price of development should not be borne by the biological diversity of any nation. Forests are considered the storehouse of biodiversity, and the shrinking forests and marine ecosystems have led to escalating losses of biodiversity in India. Identifying the causes can help in developing mitigation measures. Irrespective of the hurdles faced in curbing biodiversity loss, the situation may take a detour with active public participation and awareness regarding the need and the value of biodiversity in our day-to-day life. Developing and implementing solutions for these causes of biodiversity loss will relieve the pressure on species and maintain the proper functioning of an ecosystem and its services.

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Part VI
Efforts Conservation

Chapter 22
Conservation of National Biodiversity: Efforts of the Indian Government

Sonia Rathee and Shalinder Kaur

22.1 Introduction

Biodiversity conservation and using natural resources in a sustainable manner has always been a part of India's moral code of conduct. India comprises a huge diversity of ethnicities, and approximately 4635 ethnic communities are found across the Indian subcontinent (Maiti and Maiti 2017). These communities have been known for their harmonious coexistence with nature and protection and maintenance of the country's diverse, rich, profuse cultural, and spiritual heritage. To date, such traditional practices of ethnic communities are conducted with great regard. Variety in eco-climatic regimes along with its distinctive geographical features has blessed the country with diverse habitats like terrestrial and marine ecosystems. With about 2.4% of the world's landmass, India boasts a high percentage of recorded species, of around 7–8%. India's rich biodiversity can be easily assessed from the fact that India ranks ninth in avian, seventh in mammals, and fifth in reptile diversity (PIB 2014). India harbours four biodiversity hotspots, namely, the Himalayas, Indo-Burma, Sundaland and the Western Ghats & Sri Lanka. In terms of endemism, India's position is tenth in avian biodiversity with 69 species, fifth in reptiles with 156 species, and seventh in amphibians with 110 species (PIB 2014). However, nowadays an unprecedented biodiversity decline has been observed in India. The decline in biodiversity is a complex issue, resulting due to a multitude of factors. Fragmentation and loss of habitat, unsustainable developmental practices, climate change, the introduction of invasive species, overexploitation, and pollution have been identified as the major drivers responsible for biodiversity loss (Johnson et al. 2017). From a historical perspective, with the ascent of colonial rule in the nineteenth century, the demand for timber and land rose for industrial purposes (NBAP 2019). The Forest

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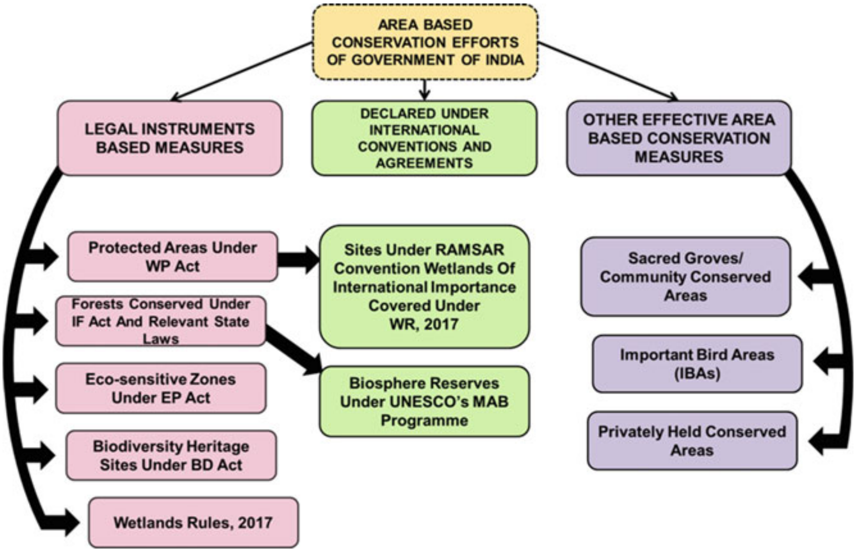

Fig. 22.1 Area based conservation measures of the Government of India. (Adapted from NBAP 2019)

Policy, which was brought into force in 1894, sought out these needs, thus further destabilizing the intricate balance between man and forest (NBAP 2019).

For a country as populous as India, conserving biodiversity is crucial not only because of the goods and services obtained (necessities of survival) but also because it provides direct or indirect livelihood opportunities for millions of people and helps to elevate their socioeconomic status. Yet, only a meager percentage of the total population realizes the importance of biodiversity and the role it plays in their lives. The Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA), 2005, is the world's largest social security scheme, and since its establishment, around five million jobs have been created in the green sector, like afforestation activity, land development, harvesting of water, etc. (MGNREGA 2005) Most poverty alleviation programs in India are increasingly looking upon the forest sector for their support.

The most pressing issue for nations and their governments worldwide is to conserve biodiversity from extinction and ensure sustainable use of these resources. The most serious challenges for the Government of India (GOI) since the past century are to balance livelihood needs and support the growing population of the country, along with the conservation of biodiversity. For this, a series of measures both at international and national/regional levels have been commenced by the GOI for monitoring biodiversity conservation and sustainable use of resources.

As per the guidelines of the Convention on Biological Diversity (CBD), national and legislative policies have been formulated in terms of NBSAP (National Biodiversity Strategies and Action Plan). For their effective implementation in curbing the loss of biological diversity, these policies are being monitored and supervised at each level (regional level to national level) (Fig. 22.1) (Kapoor and Usha 2020). Biodiversity conservation is, as stated above, an inter-sectoral and complex procedure in India. National Biodiversity Action Plan (NBAP 2008) and Addendum 2014 to NBAP 2008 (2014) are the only document of strategic policy, which were brought into force to implement its objectives through relevant ministries. Public funding was and still is the major source of funding for biodiversity conservation. The Ministry of Environment, Forests and Climate Change (MoEF&CC), state governments, and 24 other Ministries/Departments of the Government of India are the agents through which the financial resources are made available for various schemes and programs. The Biodiversity Finance Initiative (BIOFIN) was launched in India in 2015. According to the BIOFIN estimate, India's total domestic biodiversity expenditure is 59,248.09 crores for the year 2016–2017 (NBAP 2019). BIOFIN is a UNDP-managed global partnership, led in India by MoEF&CC and hosted by NBA (National Biodiversity Authority) to analyze the drivers responsible for biodiversity loss and discover financial solutions to obtain favorable results for both the society and biodiversity (NBAP 2019).

22.2 Initiatives at the International Level

India is one of the parties to participate in the following organizations and conventions that have been associated with biodiversity conservation.

- *Convention on International Trade in Endangered Species of Wild Fauna and Flora* (*CITES*): Its goal is to secure wild animals and plants during international trade so that their survival is not threatened. It ensures varying stages of protection to approximately more than 38,700 species of animals and plants worldwide. On top of that, it functions by providing a framework for its member party. The party must formulate and adopt its own domestic legislation to make sure that CITES is implemented in the country in a proper manner. CITES came into force on 1 July 1975. India is ratified as a party in the agreement on 20 July 1976.

- *Convention on Biological Diversity* (*CBD*): The CBD is an international legally binding treaty with the collective goal to encourage biodiversity conservation and related actions in the direction of a sustainable future. Through Cartagena Protocol on Biosafety, biotechnology along with other aspects of biodiversity is also covered. The body that governs the CBD is called the Conference of the Parties "COP." CBD calls forth each party to form a

National Biodiversity Strategy and Action Plan (NBSAP) to carry out its objectives. The strategy and action plan of each party should be according to their capabilities and situations. The convention was presented for signatures on 05/06/1992, entered into force on 19 December 1993, and India became a party in 1994.

•*Ramsar Convention on Wetlands of International Importance*: The Convention provides the parties with framework for conservation and sustainable usage of wetlands. Currently, India has 49 Ramsar Sites (as of 1 February 2022) covering a surface area of 11,650.553 km^2. The parties commit to designate new wetlands, their management, ensure sustainable use of their wetlands, and cooperate on international stage on shared and trans-boundary wetland systems. The convention was signed on 2 February 1971 and came into force on 21 December 1975. India became a party to the Convention on 1 February 1982.

•*United Nations Convention to Combat Desertification* (*UNCCD*): The convention is the only agreement that legally binds the environment and development to sustainable usage and management of land. The convention focuses on drylands and addresses desertification and issues of drought. UNCCD encourages local participation in tackling the issue of desertification. UNCCD also works in close association with CBD and the United Nations Framework Convention on Climate Change (UNFCCC) to fulfill its objectives in an integrated manner. UNCCD was adopted on 17 June 1994. India ratified the convention on 17 December 1996.

•*International Plant Protection Convention* (*IPPC*): IPPC is a multilateral environmental agreement (MEA) including 180 countries. Its objective is to safeguard plant resources of the world from pests and to promote its safe trade. It is the only global organization that has set a standard for plant health in form of International Standards for Phytosanitary Measures (ISPMs). The treaty was adopted in 1951.

- *Convention for the Protection of World Cultural and Natural Heritage*: Also known as World Heritage Convention, it links conservation of nature and cultural properties together. The Convention helps the member parties in the identification of potential sites and their preservation. The member party is liable to preserve World Heritage Sites and their national heritage. The convention encourages its members to strengthen public perception for the protection of World Heritage sites through different programs. Currently, India has 32 cultural, 7 natural, and 1 mixed world heritage sites. The convention was adopted on 16 November 1972. India ratified the convention on 14 November 1977.
- *Bonn Convention on Migratory Species of Wild Animals (CMS)*: The Bonn convention is also known as Convention on Migratory Species (CMS). Its main objective is the protection of migratory species (terrestrial, aquatic, and avian) throughout their migratory range. It specifies the legal guidelines for the parties to promote international coordination in conservation efforts. The convention also cooperates with other international organizations, NGOs, corporate sectors, and media. The convention came into force on 1 November 1983 and within the same year, India became a party.
- *Vienna Convention for the Protection of the Ozone Layer and the Montreal Protocol on Substances that Deplete the Ozone Layer*: The convention focuses on principles of protection of the ozone layer that has been agreed upon by its member parties, but the convention does not demand of them to take any sort of actions to control ozone layer depletion. The action on this part is specified under the Montreal Protocol. In this way, the convention hoped the member parties would amend their ways and adopt measures to protect the ozone layer. The Vienna Convention came into force on 09/22/1988 and the Montreal protocol came into effect on 1 March 1989. India ratified the Vienna convention on 18 March 1991 and the Montreal Protocol on 19 June 1992.

•*Basel Convention on Transboundary Movements of Hazardous Wastes and Their Disposal*: The aim of the convention is to protect humans and the environment from the ill effects of hazardous wastes. It promotes reduction in the generation of hazardous waste, restricts their transboundary movement of waste, and forms a regulatory system for exceptional cases where such movements are required. It is prohibited to export hazardous waste to Antarctica, or to a non-member party, or to a party that has banned the import of such waste. The convention was adopted on 22 March 1989. India ratified the convention on 24 June 1992.

•*United Nations Framework Convention on Climate Change* (*UNFCCC*): UNFCCC is an international treaty worked out at the Earth Summit 1992 (3 to 14 June 1992). Its main objective is to "*stabilize greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system*." The treaty only provides the member parties with a framework of protocols that help them set limits on the emissions of greenhouse gases. The UNFCCC was signed in 1992 in Rio de Janeiro. Under the convention, the Kyoto Protocol was formed in 1997. India ratified the UNFCCC on 1 November 1993 and Kyoto Protocol on 11 December 1997.

•*Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade*: The objective is to encourage collaboration between the member parties involved in the international trade of hazardous chemicals and pesticides. The aim is to safeguard human and environmental well-being by guiding the decision-making process for import/export. The convention was adopted on 10 September 1998. India ratified the convention on 24 May 2005.

•*Stockholm Convention on Persistent Organic Pollutants*: The Stockholm Convention is a treaty agreed upon by member parties to protect humans and the environment from persistent organic chemicals/pollutants which get distributed all over the world and subsequently enter the food chain, where it causes health hazards. The convention was adopted on 22 May 2001. India ratified the convention on 13 January 2006.

•*International Whaling Commission* (*IWC*): The commission was set up on 2 December 1946 for the conservation of whales and management of whaling. The "schedule" of the IWC lays out specific measures and steps that the commission has designated as necessary for the regulation of whaling and the conservation of whale stocks. India became a party to the IWC on 9 March 1981.

•*International Treaty on Plant Genetic Resources for Food and Agriculture* (*ITPGRFA*): The objective of the treaty is to conserve plant genetic resources for food and agriculture and use them in a sustainable manner, accompanied by fair sharing of revenues and other benefits. It requires the member parties to conform their laws and actions to their obligation toward the objectives of the treaty. The treaty was adopted on 11 March 2001. India ratified the treaty on 10 June 2002.

•*United Nations Law of the Sea Convention* (*UNCLOS*): UNCLOS was formed to establish boundaries along the coastline, monitor seabed exploration, and ensure the proper distribution of resources. As per the law, twelve nautical miles from the baseline along the coast was agreed upon as a territorial sea for the member parties. The convention was adopted on 10 December 1982. India ratified UNCLOS on 29 June 1995.

Apart from the international agreements mentioned above, India is also associated with many other international organizations related to biodiversity—International Union for Conservation of Nature (IUCN), United Nations Environment Programme (UNEP), World Conservation Monitoring Centre (WCMC), The Worldwide Fund for Nature (WWF), Global Environment Facility (GEF), United Nations Educational, Scientific and Cultural Organization (UNESCO), and The World Resources Institute (WRI).

22.3 Initiatives Taken at National Level

22.3.1 Policy Framework Established by GOI

- *National Forest Policy (NFP), 1988*: It strives to attain environmental stability, restore ecological balance, and maintain atmospheric equilibrium to allow benefits from forests without disturbing other goals and to bring about 33% of the landmass under forest cover.
- *National Environment Policy (NEP), 2006*: Its aim is to clarify the purpose of conservation and enhance the focus on the environment in sectoral policies. It commits to fulfill the objectives of international environment agreements to which India has ratified as a party. It focuses on creating guidelines for sectoral policies, preparing action plans for environmental concerns, encouraging partnerships with stakeholders, NGOs, institutes, etc., and ensuring harmony in issues concerning the environment.
- *National Agroforestry Policy, 2014*: Its major goal is to create synergy between tree plantation, livestock, and crop needs in order to alleviate poverty, provide income, achieve sustainable agriculture, and increase vegetation and forest cover along with contributing in the direction of conserving natural resources and forests.
- *National Policy on Marine Fisheries (NPMF), 2017*: Its goal includes management of fisheries for sustainable development and socio-economic upliftment of people, achieving intergenerational equity, highlighting biodiversity conservation by adopting a more environmentally conscious approach to management, prioritizing conservation of Ecologically and Biologically Significant Areas (EBSAs) and Vulnerable Marine Ecosystems (VMEs), conserving threatened and endangered species, and harmonizing with tenurial rights of fishermen. The policy recognizes the representation of women in the workforce (66%) and focuses keenly on their specific needs and overall development.

22.3.2 Legislative Framework Established by GOI

Following are the Acts that are directly linked with elements and issues associated with biodiversity:

- *Indian Forest Act (IF Act), 1927*: It includes the criteria and modalities required for designating forests for conservation and legal purposes, managing produce obtained from forests, and monitoring the matters of fees and duties regarding the exchange and movement of forest products. The Act was last amended in 2017.
- *Wildlife (Protection) Act (WP Act), 1972*: Through this Act, the state governments are allowed to designate an area as a protected area (National Parks, Wildlife Sanctuaries, Community Reserves, and Conservation Reserves) based upon its ecological importance. The Act was last amended in 2006.

- *Forest (Conservation) Act (FC Act), 1980*: The main purpose of this Act is to govern the use of forest land for non-forest-related activities. Before diversion of forest land for a non-forest activity, the idea is thoroughly scrutinized and recuperation of net present value and afforestation to compensate for diversion are alluded.
- *Environment (Protection) Act (EP Act), 1986, amended 1991*: It includes all issues related to the environment and permits the state to take steps for environmental protection, whenever necessary. On these guidelines, Coastal Regulation Zone Notification (CRZN) was issued which declared Coastal Regulation Zone (CRZ) for monitoring activities in coastal zones. In this way, conservation and protection of coastal ecosystems and local community livelihood are achieved.
- *The Protection of Plant Varieties and Farmers Rights Acts, 2001*: The Act has set up a system to protect various plant varieties, recognizing the varieties that have been evolved and cultivated traditionally by farmers, recognizing the wild relatives of plant varieties with which the local farmers are well versed, and encourage the development of new species. In addition, it also serves to protect the rights of farmers and plant breeders as per their contribution to the cause of improvement, conservation, and development of new varieties.
- *Biological Diversity Act (BD Act), 2002*: The Act was established to implement the objectives set by CBD. The Act provides for "conservation of biological diversity, sustainable use of its components, and fair and equitable sharing of the benefits arising out of the use of biological resources and for matters connected therewith or incidental thereto."
- *The Plant Quarantine Order, 2003*: The act focuses on avoiding the introduction of diseases, exotic pests, and weeds that may enter the country through the import of plant or agricultural materials. For this purpose, 61 Plant Quarantine Stations (PQSs) are established all over India.
- *The Scheduled Tribes and Other Traditional Forest Dwellers (Recognition of Forest Rights) Act, 2006 (Forest Rights Act, 2006)*: Within this Act, rights and occupation in forests are vested upon the forest-dwelling Scheduled Tribes and other traditional forest dwellers. The Act also strives to generate a balance between rights and responsibilities regarding maintenance, sustainable usage, and protection of forests along with ensuring that the food security and livelihood of the forest dwellers are not harmed.
- *The National Green Tribunal Act (NGT), 2010*: For the efficient and effective dissolution of cases related to the protection of the environment, natural resources, and forests, the National Green Tribunal Act (NGT) was established.
- *Wetlands (Conservation and Management) Rules, 2017*: These Rules were established to succeed the Wetland (Conservation and Management) Rules, 2010, with an objective to make states accountable for the conservation and sustainable management of wetlands. In these rules, the two major components of wetlands, land and water as per the constitution, are recognized to be state subjects.

22.4 In Situ Method of Biodiversity Conservation

In in situ conservation, the biodiversity (plant and animals) is conserved on-site in natural populations and in their natural habitats (Fig. 22.2).

- *National Parks*: It is a protected area (present inside or outside of sanctuary) which is regulated by the State government. This area is important in terms of its flora, fauna, geomorphology, and ecology, and is meant to protect and conserve wildlife within its premises. The Human activity of any kind is prohibited in a national park. Currently, there are 104 National Parks in India.
- *Wildlife Sanctuaries*: It is an area covered with reserve forests or territorial water for protecting biodiversity. Some limited human activities are permissible inside a wildlife sanctuary. Currently, there are 566 wildlife sanctuaries in India.
- *Eco-sensitive Zones* (*ESZ*): These are areas within a 10 km radius of any protected area like National Parks or Wildlife Sanctuaries. The objective of establishing ESZ is to regulate activities happening around protected areas and minimizing their negative impacts by acting as a shock absorber, thereby minimizing forest degradation and human–animal conflict. Approximately 283 Protected areas receive additional protection by means of Eco-sensitive zones covering a surface area of 30,349.63 km^2 (MoEFCC).
- *Conservation Reserves and Community Reserves*: These terms are denoted to the protected areas which generally connect other protected areas like reserved or protected forests, national parks, and wildlife sanctuaries. Uninhabited areas which are completely owned by the government but used by local communities are termed conservation reserves. On the other hand, if some parts of the areas are privately owned, then they are termed as community reserves. Such areas were established due to instances of lower protection around protected areas because of private ownership. At present, 97 conservation areas have been notified, whereas 987 sites have been placed under the protected area concept.

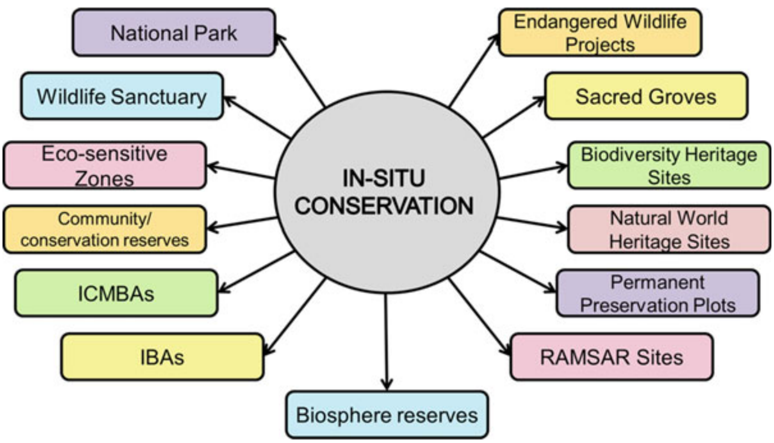

Fig. 22.2 In situ conservation methods

- *Important Coastal and Marine Biodiversity Areas* (*ICMBAs*): Some portions of coastal and marine areas of the country are designated as ICMBAs with the aim of conserving the biodiversity of these areas. A total of 106 sites have been identified by WII (Wildlife Institute of India), of which, 62 are present along the west coast and 44 along the east coast of the country.
- *Important Bird Areas* (*IBAs*): IBAs are conservation areas of birds at different global, regional, or subregional levels. The objective of IBA programs is to identify, protect, and conserve bird diversity through international networking. As the IBAs consist of a range of habitats, therefore they are proven to be efficient in indicating biodiversity richness. A total of 467 such IBAs have been identified in India.
- *Biospheres reserves—terrestrial and marine*: These reserves are recognized under Man and the Biosphere Programme (MAB) of UNESCO. These are aimed at sustainable development through local participation and scientific research. There are 18 biosphere reserves (14 as per UNESCO-MAB) in India. The Nilgiris is the oldest reserve in India, while the largest is the Kachchh (12,454 km^2) encompassing parts of Kachchh, Rajkot, Surendra Nagar and Patan Civil Districts of Gujarat State. These are undisturbed natural sites that have been selected for research, environmental education, training, promotion of sustainable use of biotic resources, and conservation purposes. A biosphere reserve constitutes three zones: Transient zone, Buffer zone, and Core Zone. No human activities are allowed in the core zone; in the buffer zone, activities like research and education are allowed; while in the transient zone, activities like recreation, forestry, human settlement, etc., are permitted.
- *Ramsar Wetlands Sites*: Currently, there are 49 Wetlands in India with a surface area of 11,650.553 km^2. Sunderbans wetland (West Bengal) is the largest (4230 km^2), whereas Renuka wetland (Himachal Pradesh; 0.2 km^2) is the smallest; and Chilka lake (Orissa) and Keoladeo Ghana NP (Rajasthan) are the oldest (recognized on 10 January 1981).
- *Permanent Preservation Plots* (*PPP*): These nature reserves are forest areas intended for the preservation of forests, permitting only those human activities related to the protection and management of these areas.
- *Natural World Heritage Sites*: These sites are important as they provide shelter to many species, protect ecological processes and landscape, contribute to the economy, provide climatic stability, and increase human wellness. There are seven recognized Natural World Heritage Sites in India.
- *Biodiversity Heritage Sites* (*BHS*): BHS are the areas having unique and fragile ecosystems in addition to harbouring rich biodiversity, and fulfilling one or more of the required criteria, i.e., high degree of endemism, presence of species having rare and threatened status, species having evolutionary significance, keystone species, wild ancestors of existing species, and fossil beds. In addition, these sites should have cultural, aesthetic, or ethical values with or without a long history of human association. The goal of empowering local communities can be achieved through the conservation of such sites. Till date (1 August 2020) 18 such sites have been recognized in the country.

- *Sacred Groves*: These are the patches of natural vegetation protected by local communities because of their religious beliefs. They contribute to conservation of biodiversity, regulation of temperature, recharging of natural aquifers, enhancement of soil stability, carbon sequestration, and conservation of traditional knowledge.
- *Medicinal Plant Conservation Areas* (*MPCAs*): These are the stretches of vegetation encompassing diverse microclimatic zones and habitats, generally located in wildlife sanctuaries and forest reserves. These are established with the aim to conserve medicinal plants and their gene pool in their natural habitats.
- *Medicinal Plant Development Areas* (*MPDAs*): These are developed for the production of medicinally important plants, where the forest department and local communities share the profits through harvesting of such plants in a sustainable manner.
- *Wildlife Protection Projects*: Several species-specific wildlife projects have also been launched by the GOI.

  – *Project Tiger*: The initiative was launched in 1973, covering nearly 2.21% of the land area. The tiger reserves are based on a core zone and buffer zone strategy. Core areas have legal status as provided to the national parks and wildlife sanctuaries, whereas buffer zones are a mix of forest and non-forest land. The core area is exclusively for tiger conservation motives. There are a total of 52 tiger reserves in India to date (1 February 2022).
  – *Project Elephant*: Project Elephant was launched in 1992. It seeks to provide support (both financial and technical) to states having elephant populations, for the welfare of elephants, along with addressing and mitigating human–elephant conflicts. The project is active through 32 elephant reserves in 14 states and Union territories of India.
  – *Gir Lion Project*: It was established in March 1972 by the Govt. of Gujarat. A 5-year plan was prepared for this project. Currently, the population of the Asiatic lion has reached 674 according to a census conducted in 2020 (Gujarat Forest Statistics, 2020–2021).
  – *Crocodile Breeding Project*: It was implemented in early 1975 for Gharial and Saltwater crocodile conservation in Odisha. Its main goal is to conserve the existing crocodilian population by creating sanctuaries, using the rear-and-release method to rebuild the population, promoting captive breeding, training the workforce, and involving the local communities for the smooth continuity of the project.
  – *Sea Turtle Project*: Wildlife Institute of India (WII) carried out a UNDP–GOI sea turtle conservation project. It was started in November 1999 and is implemented in 10 coastal states with an emphasis on Odisha. The objective was to assess the status and various threats to turtles along the coastline of India.
  – *Snow Leopard Project*: It was started in 2009 in five states (Himachal Pradesh, Sikkim, Arunachal Pradesh, Uttarakhand, J&K) to conserve endangered snow leopard species, which are the flagship species of mountains. The goal is "to safeguard and conserve India's unique natural heritage of high-altitude

wildlife populations and their habitats by promoting conservation through participatory policies and actions".
- *Project Hangul*: The project was launched in 1970 by IUCN/WWF/State of Jammu and Kashmir, India, to conserve and protect the critically endangered Hangul (Kashmir Stag).
- *Himalayan Musk Deer Project*: It was initiated as a part of the "Threatened Deer Programme" of the IUCN. In India, it was launched by WWF and GOI to conserve the white-bellied musk deer or Himalayan musk deer. The project first started in the Kedarnath Sanctuary, Uttarakhand (India).

22.5 *Ex Situ* Method of Biodiversity Conservation

Ex situ method of conservation involves maintaining the population of endangered species and their breeding under human supervision within establishments like zoological parks, botanical gardens, gene banks, aquaria, tissue culture labs, and long-term captive breeding (Fig. 22.3). These are discussed hereunder:

- *Zoological Parks*: Animals are kept in semi-natural areas in enclosures or in the open for public display. They contribute to biodiversity conservation by generating public awareness, propagation, and reintroduction of species that are threatened in nature. Some important zoological parks of India are Sri Venkateswara Zoological Park (Tirupati), Arignar Anna Zoological Park (Chennai), Nandankanan Zoological Park (Bhubaneswar), Indira Gandhi Zoological Park (Visakhapatnam), and National Zoological Park (Delhi), etc.
- *Aquaria*: It is an artificial water habitat for marine and freshwater organisms. Aquaria contribute to biodiversity conservation by captive breeding of threatened species and generating public support and awareness. Some important aquaria in India are Star aquarium (Kerala), Calcutta Aquarium (Kolkata), Marine Biological Research Station (Ratnagiri, Maharashtra), etc.
- *Botanical Gardens*: Botanical gardens are places with the collection of living plants either grown in the open or in greenhouses for research and recreation purposes. The botanical gardens are instrumental in scientific research, disseminating knowledge, conservation of plants, and recreation of the public that come to visit these gardens. Acharya Jagadish Chandra Bose Indian Botanic Garden (Shibpur, Howrah, West Bengal) is the largest and oldest botanical garden of

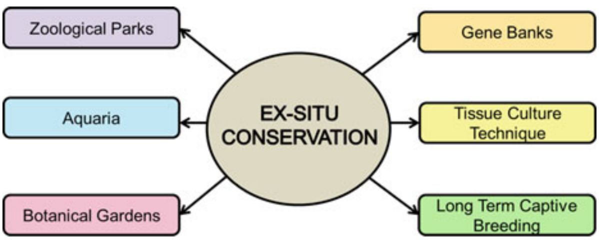

Fig. 22.3 Ex situ conservation methods

India. Other prominent botanical gardens are Lloyd botanical garden (Darjeeling), Garden of Indian Agricultural Research Institute (New Delhi), and Lalbagh botanical garden (Bengaluru), etc.

- *Medicinal Plant Conservation Parks* (*MPCPs*): The main aim of MPCPs is to conserve the diversity of medicinally important plants through ex situ methods. These parks can provide the raw material for medicinal drugs and seeds for horticulture and cultivation purposes. These are potential centers for training and educating the local community and may include herbariums.
- *Gene Banks*: It is a facility to store plant/animal materials to protect them from extinction and preserve them in viable conditions. The material can be stored as either seed/semen/ovule/pollen/DNA or as any other plant tissue at -196 °C to safeguard them from extinction and to develop new varieties when needed. There are a number of such repositories in India, e.g., Botanical Survey of India, Kolkata (plants), National Bureau of Animal Genetic Resources, Karnal, Haryana (Animals), National Institute of Virology, Pune (Virus), and National Institute of Oceanography, Goa (Marine flora and fauna), etc.
- *Tissue Culture Technique*: This technique helps to conserve specific parts instead of the whole living organism. A huge quantity of genotypes and animal germplasm can be stored in a small space, and the endangered species can be protected with the possibility of reintroducing them into nature.
- *Long-Term Captive Breeding*: It is an important aspect of the conservation process of any species, variety, population, etc. Captive breeding has several contributions to biodiversity conservation like, sufficient stock of an organism under care for reintroduction, disseminating knowledge and awareness, husbandry research, etc.

22.6 Efforts by the GOI to Generate Awareness and Sensitize the General Public for Biodiversity Conservation

National Biodiversity Targets (NBT) includes Communication, Education and Public Awareness (CEPA). The objective is to make the public aware of the importance of biodiversity and subsequently be able to take decisions towards conservation and sustainable use of biodiversity.

- *Creating Awareness in the Youth and Children*: Environmental Education has been included and made compulsory in every academic syllabus. In addition, a variety of co-curricular programs like Paryavaran Mitra Programmes, National Nature Camps, and Eco-clubs are supported by the government at the national and state levels.
- *Creating Awareness in the Industrial Sector*: IBBI (India Business and Biodiversity Initiative) was initiated in collaboration with Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ). MoEF&CC facilitated this programme for boosting awareness efforts and promoting green actions.

- *Creating Awareness in the Local Communities and Institutions of Local Governance*: Workshops are conducted, guidelines are issued, and communication is encouraged between local communities/governance, State Biodiversity Boards (SBBs), and NBA. As a result of the efforts of the GOI, total Biodiversity Management Committees (BMCs) has now reached >1,44,000 in number.
- ENVIS (Environmental Information System) was created by MoEF&CC, and it comprises a network of 69 ENVIS Hubs and Resource Partners. Out of these, 29 are engaged in dealing with 'State of the Environment and Related Issues'.
- Several databases have been set up for documenting Indian biodiversity:
  - E-flora of India (BSI)
  - Flowers of India
  - Marine Mammal Conservation Network of India
  - Indian Biodiversity Information System
  - India Biodiversity Portal
  - Birds of India
  - India Birds
  - Mammals of India
  - Biodiversity of India
  - Indian Medicinal Plants Database
- In addition, MoEF&CC and NBA organize awareness programs on national and regional levels in association with SBBs, NGOs, and Central Statistical Organization for various stakeholders.
- MoEF&CC and United Nations Development Programme (UNDP) have instituted the Biennial India Biodiversity Awards. Similarly, E.K. Janaki Ammal National Award has also been instituted for individuals for extraordinary contribution in plant, animal, and microbial taxonomy. In addition, MoEF&CC has instituted several awards for the conservation and protection of biodiversity, environment, and Wildlife. These include Amrita Devi Bishnoi Wildlife protection Awards, B.P. Pal National Environment Fellowship Award for Biodiversity, Desert Ecology Fellowship, Indira Priyadarshini Vriksha Mitra Awards, National Awards for Excellence in Forestry, Shri Kailash Sankhla National Wildlife Fellowship Award, Dr. Salim Ali National Wildlife Fellowship Award, National Environmental Sciences Fellows Programme, Pitambar Pant National Environment Fellowship Award, Paryavaran aur Van Mantralaya Vishisht Vaigyanik Puraskar, Rajiv Gandhi Wildlife Conservation Award.

22.7 Government Encourages Research & Development (R&D) Efforts for Biodiversity Conservation

- NBAP is integrated with departments, programs (planning and development), and institutions (technical and scientific).
- MoEF&CC sponsors and funds many research projects all over India, for working on the aspect of biodiversity conservation.

- To combat organized crime against wildlife, Wildlife Crime Control Bureau was established under MoEF&CC.
- Under the scheme 'Integrated Development of Wildlife Habitat (IDWH)', sponsored by the Central Government, several species were identified for species recovery program (ENVIS):
  - Asiatic Lion
  - Swamp Deer
  - Jerdon's Courser
  - Nilgiri Tahr
  - Snow Leopard
  - Dolphin
  - Edible nest Swiftlet
  - Great Indian Bustard
  - Hangul
  - Marine Turtles
  - Nicobar Megapole
  - Asian Wild Buffalo
  - Brow-antlered deer
  - Vultures
  - Malabar Civet
  - Indian Rhinoceros
  - Dugong
- Special organizations like Wildlife Institute of India (WII, DehraDun, Uttarakhand), Bombay Natural History Society (BNHS, Mumbai, Maharashtra), Salim Ali Centre of Ornithology and Natural History (SACON, Coimbatore, Tamil Nadu) were established to train individuals for management and conservation of wildlife, spread awareness, and build scientific knowledge.
- Prime Minister's Science, Technology and Advisory Council (PM-STIAC) initiated the National Biodiversity Mission with the aim to highlight biodiversity conservation in Indian policy, science, and society.
- National Knowledge Commission (NKC)—India Biodiversity Portal aims to provide and collect information on Indian biodiversity through public participation.
- Laboratory for conservation of endangered species (LaCONES), a dedicated facility established "*to promote excellence in conservation biotechnology and serve for conservation of endangered wildlife in India*."
- Under G-15 initiative, three national gene banks were established at *Central Institute of Medicinal and Aromatic Plants* (CIMAP; Lucknow), *National Bureau of Plant Genetic Resources* (NBPGR; Delhi), and *Jawaharlal Nehru Tropical Botanical Garden and Research Institute* (JNTBGRI, Thiruvananthapuram).
- The GOI has also launched 'secure Himalaya', a 6-year project in association with UNDP for conservation of globally and locally important biodiversity, land, and forest wealth of the Himalayan ecosystem, for securing the livelihood of people local to the area and for lessening wildlife crimes.

22.8 Conclusions

Conserving biological diversity is a complex process. "*We do not inherit the Earth from our ancestors—we borrow it from our children*" is a popular saying. This sentiment should resonate with every citizen of the country. The Government of India has established various policies and legislative frameworks over the years and is diligently implementing them, making its stance on biodiversity conservation very clear. However, the end goal cannot be achieved by the efforts of any government alone unless the local communities support the same vision. The efforts at the administrative levels, along with public support, will help in the conservation of species and sustainable use of available resources.

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Chapter 23
Legal Framework for Conservation of Biodiversity in India

Tarun Arora

Abbreviations

Art.	Article
Arts.	Articles
BMCs	Biodiversity management committees
CBD	Convention on Biological Diversity, 1992, CoI: Constitution of India
Cl.	Clause
FEBS	Fair and equitable benefit sharing
GoI	Government of India
LMO	Living modified organisms
MOEF	Ministry of environment and forests (later on, name changed as MoEFCC)
MOEFCC	Ministry of environment, forests and climate change
NBA	National biodiversity authority
r/w	Read with
r	Rule
s.	Section
ss.	Sections
SBB	State biodiversity board

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23.1 Introduction

Humankind entered the new millennium with a challenge to protect the life and natural resources of the planet. The international fraternity under the aegis of the United Nations (UN) has been striving consistently to preserve the natural resources for the present as well as future generations to honour the mandate of the United Nations Conference on Human Environment since 1972. In the wake of development, over-exploitation and unsustainable use of natural resources threatened the existence of flora and fauna the Act has, also been addressed as the 'web of life' (Rajya Sabha 2002). India is not immune to the adverse effects of an unsustainable pattern of consumption and development. Responding to the call of the UN (Convention on Biological Diversity 1992) and constitutional obligation (Art. 48-A, The CoI), the Government of India (GoI) adopted a multipronged strategy for the preservation of its 7.8% of the recorded species on 2.5 per cent land area of the world (Rajya Sabha 2002). Art. 48-A and Art. 51-A (g) were introduced by 42nd Constitution Amendment Act, 1976 to specify the obligation of the State and the citizens respectively to contribute to the protection and improvement of the natural environment, including forests, lakes, rivers, and wildlife, and compassion for living creatures (The CoI, 1950). There are around 36 laws dealing, directly or indirectly, with various components of biodiversity (CEERA 2019). However, the prominent measures taken by India in Post CBD are as under:

1. The Biological Diversity Act, 2002
2. National Wildlife Action Plan, 2002–2016
3. National Environment Policy, 2006
4. National Biodiversity Action Plan, 2008
5. National Action Plan on Climate Change, 2008

In order to comply with the international obligation stated under Art. 6 of the CBD to take strategic measures, plans, and programmes for conservation and sustainable use, the GoI introduced the above plans and policies. The scope of discussion in this chapter has been confined to legal and regulatory aspects of the protection of biodiversity in India with special reference to The Biological Diversity Act (2002) and the Rules framed thereunder. The significance of this Act was underlined by the renowned jurist Sh. L.M. Singhvi by addressing it as *Charter of Ecological Security* (Rajya Sabha 2002). Conservation and sustainable use of biodiversity is possible with the interface between science, technology, and law. The forthcoming discussion aims at developing the basic understanding of readers about The Biological Diversity Act (2002) (the Act), its inter-disciplinary aspects, and implications for the research fraternity from science, technology, law and other disciplines involving their rights and obligations as well. For the purpose of lucid understanding, the scheme of the Act has been discussed in Fig. 23.1. The next part elaborates the operative aspects under the act with the help of rules (The Biological Diversity Rules 2004) (hereinafter referred to as the Rules, 2004) and Regulations, Notifications, and Circulars issued by the Central Government from time to time.

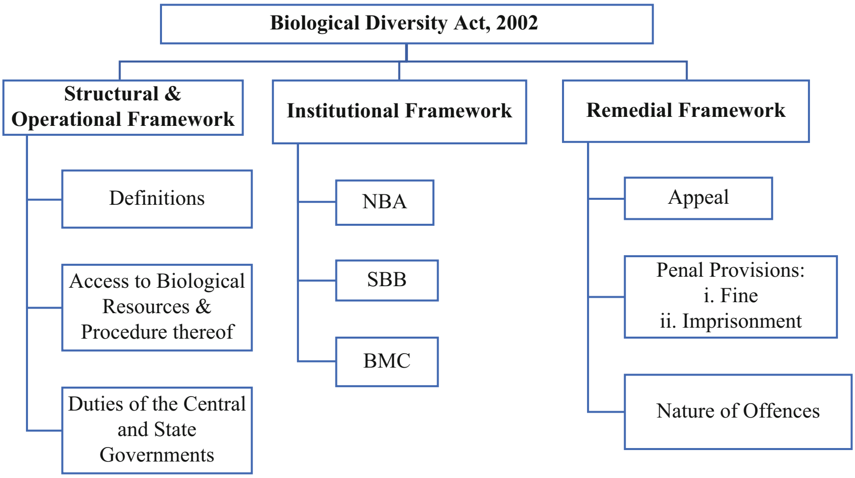

Fig. 23.1 Scheme of the Biological Diversity Act, 2002

23.2 Structural Framework

This part consists of a bird's-eye view of the preamble, scheme of the Act, the operative part containing provisions for regulation of access to biological resources and associated traditional knowledge (referred as biological wealth) followed by the duties of the governments concerning conservatory and other measures.

23.2.1 The Preamble

In modern times, the preamble of an Act plays a significant role to understand the meaning, nature, and scope of an Act. It is considered a key to opening the mind of the framers of the Act. It helps to understand the intention of the legislature behind the enactment of the Act. The preamble of The Biological Diversity Act (2002) is fairly comprehensive. It is a prefatory statement of desired objects. Acknowledging the richness of biological diversity and associated traditional and contemporary knowledge concerning it, the language of the preamble underlines threefold objectives of the Act. It envisions the role of law in the context of biological diversity as under:

1. To conserve biological diversity
2. To ensure sustainable use of its components and
3. To share a fair and equitable amount of benefits arising out of the use of biological resources and knowledge associated therewith.

The preamble mentions the obligation of the GoI to be a signatory to the UN Convention on Biological Diversity (1992) (Adoption of Agreed Text at Nairobi and opening of Convention's Text at Rio, 1992). Right on the heels of CBD recognizing the sovereign right of the nations over their own biological resources (Convention on Biological Diversity 1992), the Act reiterates the sovereignty of the GoI over the biological resources. It will not be out of context to highlight that the aims and objectives of the Act are in apt synchronization with the objectives of the CBD. Elaborating on the inter-relationship of this Act with CBD, Sh. T. R. Baalu, MoEF (now MoEFCC) expressed that being a signatory to the Convention, the GoI was under an obligation to facilitate access to its genetic properties to other contracting parties (Lok Sabha 2002). Respecting the sovereignty of the nations and recognizing their liberties to enter into a mutual agreement (Arts. 6 & 15, Convention on Biological Diversity 1992), the convention permitted contracting parties to decide terms and conditions of access to genetic resources mutually. Contracting parties have been accorded the liberty to shape their national legislations and regulatory framework accordingly. The Minister informed that India was one of 12 mega-diversity nations having pioneered such legislation in their respective jurisdictions. The convention suggested that the recipient country should comply with its obligation to share fair and equitable benefits arising from the use of genetic resources obtained from the access provider or transferor country.

23.2.2 Scheme of the Act

To pursue these objectives, the operative part of the Act is structured into 12 chapters and 65 sections. Chapter I (ss.1–2) deals with the title, extent, and commencement of the Act followed by definitions of the important words and expressions repeatedly used in the Act. Chapter II (ss. 3–7) regulates access to biological resources. In Chaps. III–VI, the institutional framework such as National Biodiversity Authority (NBA) (ss. 8–17), its functions, powers (ss. 18–19), and procedure (ss.19–21), State Biodiversity Board (SBB), its functions, powers, and other provisions (ss.22–25) have been laid down. Chapters VII & VIII prescribe provisions concerning finance, accounts, audit, and legislative control over NBA (ss.26–30) and SBB (ss.31–35), respectively. The duties of the Central and State Governments have been elaborated in Chapter IX (ss. 36–40). Chapter X enlists provisions related to Biodiversity Management Committees (BMC), their constitution, and scope of functioning (s. 41). It is followed by chapter XI titled Local Biodiversity Fund (ss.42–47). The last chapter deals with miscellaneous aspects of inter-agency coordination, provisions of punitive nature, liabilities, classification of offences, effects of this law on other laws in existence, and delegation of law-making powers to the Central Government and State Governments (ss. 48–65).

23.2.3 Operative Parts of the Act

The scope of the discussion in this part is confined to explaining the meaning and sense of a few significant and recurring expressions. S.1, as usual in practice, mentions about short title, extent, and commencement of the Act. The power was delegated to the Central Government to decide the date for commencement and the government was given the liberty to determine different dates for different provisions to come into force. Accordingly, the Act was brought into force in two stages. The first notification brought ss. 1–2, 8–17, 48, 54, 59, 62 to 65 into effect on October 1, 2003 (MoEF 2003). In the second stage, ss. 3 to7, 18 to 47, 49–53, 55–58, 60–61 were brought into effect on July 1, 2004 (MoEF 2003). S. 2 of the Act, as per the modern practice of inserting, definition Cl. in the preliminary chapter laid down 16 definitions. The words and expressions used in the enforceable part of the Act are defined here to avoid any suspicion as to their correct meaning. The purpose of including definition Cl. in the preliminary provision is to introduce the stakeholders and readers to the sense in which the legislature (law-making body) has used these expressions. The words and expressions defined under s.2 are 'benefit claimers', 'biological diversity', 'biological resources', 'bio-survey and bio-utilization', 'chairperson', 'commercial utilization', 'fair and equitable sharing', 'local bodies', 'member', 'National Biodiversity Authority', 'prescribed', 'regulations', 'research', 'State Biodiversity Board', 'sustainable use', 'value-added products'(The Biological Diversity Act 2002). Since the present book is inter-disciplinary work, therefore, a few expressions probably discussed in other parts dealing with scientific aspects of biological diversity have been skipped to avoid repetition. However, some of the expressions which are important to explain their legal implications can be elaborated as under:

23.2.3.1 "Benefit Claimers" means the Conservers of Biological Resources, Their Byproducts, Creators and Holders of Knowledge and Information Relating to the Use of Such Biological Resources, Innovations, and Practices Associated with Such Use and Application; {s.2 (a)}

Comment: The expression 'benefit claimers' has been used for ten times in the script of the Act. The object of defining this word is to recognize the contribution of persons in the conservation of biological resources and to protect their legitimate interests in a reasonable way. The use of the word *means* in the language of the provision indicates that the definition is exhaustive and comprehensive. The language of the sub-section does not specify the kind of persons, but it explains the domain of processes wherein the person involved can be recognized as benefit claimers. For the purpose of detailed explanation, dissection of the script of this sub-section reveals as under:

1. There are three types of 'persons' covered under this provision:
   a. Conservers of biological resources and by-products
   b. Creators of knowledge and information concerning the use of a biological resource, innovation, and practices associated with such use and application
   c. Holders of knowledge and information concerning the use of a biological resource, innovation, and practices associated with such use and application
2. The word person has been used in the widest sense including natural as well as a legal entity that implies a registered institution, association, or unit.

The expression 'benefit claimers' has been used seven times in the text of s. 21 of the Act, which authorizes NBA to determine the number of benefits to be shared with those who contribute to the conservation of not only biological resources but also the traditional knowledge associated thereto. Further, s. 27 also depicts the use of the expression 'benefit-claimers' wherein the provision has been made to create a National Biodiversity Fund to be used for realizing the threefold purpose of the Act, including its use for channelizing the amount to benefit claimers. The Act does take care of the procedural aspects of providing relief to the benefit claimers in case their interests are compromised or their rights recognized under ss. 21 and 27 are violated. Through s.61 (b), benefit claimers have been given the alternative to move to the court for filing a complaint against an offence under this Act after serving a notice of not less than thirty (30) days.

23.2.3.2 "Bio-survey and Bio-utilization" Means Survey or Collection of Species, Subspecies, Genes, Components, and Extracts of a Biological Resource *for Any Purpose* and Includes Characterization, Inventorisation, and Bioassay; {s.2 (d)}

Comment: The expression 'bio-survey and bio-utilization' has been used as a process of collection of various components or constituents of a biological resource for any purpose. The use of the expression '*any purpose*' in this enactment carries deep implications. The scope of this definition has been kept open for expansion to an unlimited extent by using the word '*any*' preceding kinds of purpose enumerated such as characterisation, inventorisation or bio-assay. These expressions have been used five times in the text of this Act for restricting access to biological resources for a different purpose. Whereas ss. 3 and 7 use these expressions for permissibility to access the biological resources for the purpose of bio-survey and bio-utilization, ss. 21 and 23 provide for taking into the contribution of the science fraternity in preserving the biological resources through their research and development.

23.2.3.3 "Commercial Utilization" Means-End Uses of Biological Resources for Commercial Utilization Such as Drugs, Industrial Enzymes, Food Flavours, Fragrance, Cosmetics, Emulsifiers, Oleoresins, Colours, Extracts, and Genes Used for Improving Crops and Livestock Through Genetic Intervention, But Does not Include Conventional Breeding or Traditional Practices in Use in Any Agriculture, Horticulture, Poultry, Dairy Farming, Animal Husbandry or Beekeeping; {2 (f)}

Comment: The expression 'commercial utilization' is of great significance. It has been used in the Act ten times at different places in the context of throwing light upon the purpose of accessing biological resources. Analysis of the above definition clearly highlights that the scope of accessing biological resources has been extended to the formulation and extraction of properties thereof for the formulation of drugs, industrial enzymes, food flavours, fragrances, cosmetic products emulsifiers, oleoresins, colours, etc. Furthermore, the use of extracts and genes derived from biological resources can be made to improve the productivity of crops and livestock through genetic intervention. The former part of the sub-section indicates the nature of use for commercial purposes. While the latter part of the sub-section carves out certain activities from the purview of commercial utilization such as convention or traditional practices used in various activities like agriculture, horticulture, poultry, dairy farming, animal husbandry, beekeeping, etc. The use of any bio-resource in certain specified activities shall not amount to commercial utilization and will be of free access to the persons specified in ss. 3–7 of the Act.

23.2.3.4 "Research" Means the Study or Systematic Investigation of Any Biological Resource or Technological Application, that Uses Biological Systems, Living Organisms or Derivatives Thereof to Make or Modify Products or Processes for Any Use; {2 (m)}

Comment: Out of the five expressions identified by the researcher from definition Cl., 'research' is one of the widely used expressions in the Act. The bare language of this Act depicts the use of this word 18 times in the operative part of this Act. For the purpose of research within the scope defined under the Act, the individual as well as institutions of Indian origin, in some specified cases, foreign institutions also have been permitted to access biological resources. So far as the language of this sub-section is concerned, it simply elaborates the meaning of research to carry out the systematic and orderly examination of any biological resource for any purpose or process. The Act in pursuance of Arts. 2 to 21 of the CBD has, explicitly and implicitly, given requisite significance to research activities.

23.2.3.5 "Sustainable Use" Means the Use of Components of Biological Diversity in Such Manner and at Such Rate That Does Not Lead to the Long-Term Decline of the Biological Diversity Thereby Maintaining Its Potential to Meet the Needs and Aspirations of Present and Future Generations; {2 (o)}

Comment: This expression 'sustainable use' has been defined in pursuance of the goals specified in the preamble of the Act as well as the CBD. Its purpose is to elaborate the meaning of this expression to ensure that the biological resources remain available and accessible to posterity. It aims to address the decline of biological diversity in the wake of the unplanned and irresponsible use of biological resource. The underlying idea of the expression 'sustainable use' and its use in this Act for 18 times is to promote the use of science and technology not to prove mastery over nature but to live in harmony with nature. Interpretation of the word 'long term decline' in the light of the expression 'future generations' signifies the preservation of these natural resources for those who have yet to be born. The use of the words 'such manner and at such rate' confers adequate room for the promotion of scientific techniques to plug the evil of undue and heedless exploitation of biological resources.

23.2.4 Regulation of Access to Biological Diversity

Ss. 3 to 7 under Chap. II are restrictive in nature. The CBD acknowledged that human activities are responsible for the erosion of biological resources. Studies carried out to evaluate the rates of loss, or even the current status of species revealed that no monitoring mechanism was in existence (Glowka et al. 1994). It further adversely affected the proper and effective policy formulation to conserve endangered resources. Henceforth, Art. 7 of CBD incorporates provisions for the identification of components of biodiversity requiring conservation and sustainable use as well as monitoring the processes that may cause an adverse impact on biological wealth. To effectively preserve and protect the natural resources situated within the geopolitical boundaries of India, these provisions (ss. 3–7) aim at regularizing the access to biological wealth for certain specified purposes. Open access to the biological wealth for commercial utilization, bio-survey, or bio-utilization has been curtailed for some specified persons having foreign funding, in other words, affiliation or origin, in pursuance of the exercise of the sovereign right to preserve nation's biological wealth (Arts. 6 & 15, CBD). The idea behind this restriction is to avoid activities that may unreasonably result in declining biological wealth. Unauthorized access to the biological wealth of one nation results in deprivation of its individual's natural right to avail the opportunities to grow and also affects the development of respective societies. Biological wealth can certainly contribute to the growth of economic progress and prosperity of the nation in addition to sustaining the life-cycle on this planet. With the purpose to conserve, promote sustainable use, and share benefits with respective stakeholders, the Act provides a mechanism to regulate and track unauthorized access to biological wealth. Due care has been taken to distinguish access for commercial and other purposes from access for research. The research fraternity has been given an advantageous position in the context of access to biological wealth. A detailed discussion about this regulatory framework can be made as under:

23.2.4.1 S.3-Certain *Persons* Not to Undertake Biodiversity Related Activities Without Approval of National Biodiversity Authority

(1) No *person* referred to in sub-section (2) shall, without previous approval of the National Biodiversity Authority, obtain any biological resource occurring in India or knowledge associated thereto for research or for commercial utilization or for bio-survey and bio-utilization.
(2) The persons who shall be required to take the approval of the National Biodiversity Authority under sub-section (1) are the following, namely:

  a. A person who is not a citizen of India;
  b. A citizen of India, who is a non-resident as defined in Cl. (30) of s. 2 of the Income-tax Act, 1961;
  c. A body corporate, association or organization

    - Not incorporated or registered in India; or
    - Incorporated or registered in India under any law for the time being in force that has any non-Indian participation in its share capital or management.

Comment: This provision enumerates the persons restricted to carry out activities like research, commercial utilization, bio-survey, or bio-utilization concerning bio-wealth without the prior approval of the NBA. Analysis of the above provision makes it clear that the meaning and scope of this word 'person' is not confined only to the natural persons. S. 3(2) (c) extends the scope of this provision to cover legal persons, in other words, legal entities having been recognized in the eyes of the law. Therefore, it includes a registered corporate body, association, or organization within its scope. It is significant to point out here that along with non-citizen, non-resident under S. 2 Cl. (30) of I.T. Act, 1961, any corporate body registered under foreign laws or having foreign investment in its share capital or management cannot access biological wealth without the prior approval of NBA. These persons specified in Cl. 2 have been restricted to access biological wealth within the territory of India without the NBA's approval. The NBA has adequate powers to accord, reject, or revoke the approval and to impose terms and conditions in case of approval (The Biological Diversity Rules 2004).

Procedure for Obtaining Access u/s 3: (s. 3 r/w r 14)

1. Form I is used for seeking approval to access the biological wealth in India along with a fee of ten thousand rupees in the form of cheque/dd in favour of the authority (The Biological Diversity Rules 2004).
2. The form requires specific nature of access sought and biological wealth, its identity, and details if it is used traditionally.
3. Information in case of access to associated traditional knowledge and the person holding the knowledge.
4. Time span for collecting biological resource/s.
5. Name and number of person/s authorized by the applicant for selecting the biological resource/s and collection thereof.
6. Purpose of access—research/commercial.
7. Any probable danger and risk to any component of biological wealth during access or collection.
8. Destination of research and development where the biological resource/s shall be worked upon.
9. Expected economic and other benefits associated with access and its bio-utilization.
10. A proposed mechanism for benefit sharing (The Biological Diversity Rules 2004).

The purpose behind seeking the above information is in consonance with the spirit of CBD implicit in various Arts. such as 7, 12–21, and others. Basically, the CBD imposes obligations on contracting parties to develop a mechanism for monitoring, identification of suspicious activities, and maintaining and organizing proper data concerning biological resources and activities connected therewith has been imposed on contracting parties. In addition to the above information, the applicant is expected to undertake that the collection of the proposed biological resource/s shall neither put any adverse effect on the sustainability of the resource nor entail any environmental impact. There shall be no adverse effect on either the ecosystem or local communities during the collection of the proposed biological resource/s.

The NBA has been given a time of 6 months to dispose of the application. The Act imposes an obligation on the NBA to take decisions on such application in consultation with the concerned local body. In case of a positive decision, the NBA may grant the approval on the terms and conditions, it deems fit. The approval to access is to be given in the form of a written agreement duly signed by an authorized officer and the applicant (The Biological Diversity Rules 2004). The agreement must contain detailed terms, purposes, methods, confidentiality, liability, and obligations on breach of conditions, monetary aspects along with the option of duration, termination, referring the matter in case of dispute to arbitration, and enforceability (The Biological Diversity Rules 2004). Where the NBA rejects the application for approval, it should record the reasons for rejection after giving an opportunity of being heard by the applicant (The Biological Diversity Rules 2004).

23.2.4.2 S. 4: Results of Research Not to Be Transferred to Certain Persons Without Approval of National Biodiversity Authority

No person shall, without the previous approval of the National Biodiversity Authority, transfer the *results* of any *research* relating to any biological resources occurring in, or obtained from, India for *monetary consideration or otherwise* to any person who is not a citizen of India or citizen of India who is a non-resident as defined in Cl. (30) of section 2 of the Income-tax Act, 1961 or a body corporate or organisation which is not registered or incorporated in India or which has any non-Indian participation in its share capital or management.

Explanation: For the purposes of this section, "transfer" does not include publication of research papers or dissemination of knowledge in any seminar or workshop, if such publication is as per the guidelines issued by the Central Government.

Comment: The Act forbids a person to transfer one's outcome of research based on the use of any biological wealth of India to persons referred u/s 3(2), with or without consideration, except with the prior approval of the NBA. The explanation attached to the provision clarifies publication of research papers or dissemination of knowledge in any academic event within the permissible limits by the Central Government shall not amount to the transfer of results.

Procedure for Permission to Transfer Results u/s 4: (s. 4 r/w r. 17)

1. Form II is used for seeking approval to transfer the results of research associated with biological wealth to foreign nationals, companies, and NRIs for a commercial purpose along with a fee of five thousand rupees in the form of cheque/dd in favour of the authority (s.14 [1] [2]) (The Biological Diversity Rules 2004).
2. The form seeks information about results of research carried out on biological wealth and its details, geographical location, individual or community holding biological wealth, details about institutions of R & D (The Biological Diversity Rules 2004).
3. It requires information about the details of individual/organization/s to whom the results are proposed to be transferred along with economic, biotechnological, scientific implications of commercial utilization to the transferor and transferee and details of the agreement between transferor and transferee.

The NBA is empowered to decide this application within 3 months from the date of receipt on such terms and conditions as it deems fit. Regarding the form of approval and process of rejection, the NBA possesses the same powers as explained above in comment s. 3 of the Act (s.17 [5] [6]) (The Biological Diversity Rules 2004).

Note: It is important to point out there that the provisions of ss. 3 and 4 shall not be applicable to access certain biological resources exempted by the Central Government through a notification in pursuance of India's obligation as a party to the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA). These biological resources can be exempted for the purpose of research, breeding, and training for food and agriculture by the Central Government within the purview of s.40 under normal trade commodities (MoEF&CC 2014).

23.2.4.3 S. 5: SS. 3 and 4 Not to Apply to Certain Collaborative Research Projects

(1) The provisions of ss. 3 and 4 shall not apply to collaborative research projects involving transfer or exchange of biological resources or information relating thereto between institutions, including Government sponsored institutions of India, and such institutions in other countries if such collaborative research projects satisfy the conditions specified in sub-section (3).
(2) All collaborative research projects, other than those referred to in sub-section (1) which are based on agreements concluded before the commencement of this Act and in force shall, to the extent the provisions of the agreement are inconsistent with the provisions of this Act or any guidelines issued under Cl. (a) of sub-section (3), be void.
(3) For the purposes of sub-section (1), collaborative research projects shall

   a. conform to the policy guidelines issued by the Central Government on this behalf;
   b. be approved by the Central Government.

Comment: This provision carves out certain research projects out of the scope of ss. 3 and 4. The collaborating research projects even with government-sponsored institutions of India and abroad shall not attract the provisions of ss. 3 and 4 where the policy guidelines of the Central Government are satisfied and approved by the Central Government (Central Government Guidelines for International Collaboration Research Projects 2006).

The legislative intent implicit in this relaxation is to promote the research and development to pursue the goal of conservation, sustainable use, and fair and equitable benefit sharing with stakeholders. Humankind and their attitude are certainly significant. The capability of humankind with science and technology can certainly contribute to not only conservation but also in developing sustainable use and practices. The world can reap the benefit of scientific development with a just approach (Lok Sabha 2002). It can further result in enhancement in quality and standards of life. If the potential is applied recklessly or negligently, it may do irreparable harm in the form of biocide, ecocide, homicide, ecological suicide, and genocide (Rajya Sabha 2002). Past experience has shown that no single nation can ensure the sustainable use of biological resources by itself. International cooperation is indispensable and collaborative research can play a significant role to achieve threefold objectives spelt out in international and national biological wealth legal regimes. Accordingly, Arts. 12, 16, 18, 20, and many other provisions of the CBD talked about the promotion of cooperation in research and training among the contracting parties. Therefore, the Act gives special importance to research activities, provided these are not repugnant to the spirits of the Act and the CBD. Treating the preservation of biodiversity as the cross-sectoral and cross-borders goal of humanity, the last two decades witnessed spectacular research-based skills to complement traditional conservatory practices. The tissue culture, cell fusion, embryo transfer, recombinant DNA technology, and unique bioprocessing processes have effectively resulted in preserving biological wealth. Keeping this in view, the transfer of results of research based on biological wealth and exchange of biological wealth to further collaborative research and development activities has been made permissible under this provision. However, the research projects in existence before the commencement of the Act shall stand void to the extent of inconsistency with the provisions and spirit of the Act.

23.2.4.4 S 6.: Application for Intellectual Property Rights Not to Be Made Without the Approval of National Biodiversity Authority

(1) No person shall apply for any intellectual property right, by whatever name called, in or outside India for any invention based on any research or information on a biological resource obtained from India without obtaining the previous approval of the National Biodiversity Authority before making such application. Provided that if a person applies for a patent, permission of the National Biodiversity Authority may be obtained after the acceptance of the patent but before the sealing of the patent by the patent authority concerned

Provided further that the National Biodiversity Authority shall dispose of the application for permission made to it within a period of 90 days from the date of receipt thereof.

(2) The National Biodiversity Authority may, while granting the approval under this section, impose benefit sharing fee or royalty or both or impose conditions including the sharing of benefits arising out of the commercial utilization of such rights.

(3) The provisions of this section shall not apply to any person making an application for any right under any law relating to the protection of plant varieties enacted by Parliament.

(4) Where any right is granted under a law referred to in sub-section (3), the concerned authority granting such right shall endorse a copy of such document granting the right to the National Biodiversity Authority.

Comment: The finest illustration of the contribution of the human mind in the development of modern society in contemporary times owes a great deal to IPRs. The IPRs have immensely contributed to decent living and still continue to enrich lives across the globe. As per the mandate of Art. 19 of the CBD, each contracting party shall take necessary measures for the promotion of biotechnological research activities especially in developing countries providing their biological and genetic resources for research. The Act has established a checkpoint before one moves any application for registration of IPR in India or abroad. This checkpoint under s. 6 holds great significance for the research fraternity as it underscores the role of the

NBA in according approval before filing an application for registration of IPR with the office of the registering authority. If a person wishes to proceed for registration of IPR, whether inside or outside India, for any invention based on any research or information on the use of biological wealth obtained from India, one needs prior approval of the NBA. The proviso of s. 6 eases the rigour of the main part of this provision regarding routing the application for IPR through the NBA. It permits for *post facto* approval of NBA after acceptance of the approval but before the stage of sealing the patent.

The NBA has been authorized to impose benefit sharing fee or royalty or both or impose conditions including the sharing of monetary benefits arising out of the commercial utilization of such rights. Sub-section (3) mentions that in case a person has applied for IPR under the Protection of Plant Varieties Acts, the provision of this enactment will not be invoked. The application for registration of intellectual property under the law concerning the protection of plant varieties need not be routed through the NBA. But the registering authority of such an IPR shall endorse a copy of such document to the NBA.

Procedure for Permission to Transfer Results u/s 4: (s. 6 r/w r. 18)

1. Form III is used for seeking prior approval of NBA before application for IPR.
2. It demands information about the invention worthy of IPR along with details of biological wealth used in the invention, geographical location of a resource, place of research and development activities, and economic, biotechnological, scientific, commercial implications of the invention.

This application form has to be submitted with a fee of five hundred rupees on which the NBA is authorized to decide on the application at the earliest not later than 3 months on such terms and conditions as it deems fit. Regarding the form of approval and process of rejection, the NBA possesses the same powers as explained above in comment of s. 3 of the Act.

23.2.4.5 S.7: Prior Intimation to State Biodiversity Board for Obtaining Biological Resource for Certain Purposes

No person, who is a citizen of India or a body corporate, association, or organization which is registered in India, shall obtain any biological resource for commercial utilization, or bio-survey and bio-utilization for commercial utilization except after giving prior intimation to the State Biodiversity Board concerned: Provided that the provisions of this section shall not apply to the local people and communities of the area, including growers and cultivators of biodiversity, and *vaids* and *hakims*, who have been practising indigenous medicine.

Comment: In pursuance of the threefold objectives stated in the preamble of the Act, not only the non-citizens but the citizens of India also have to comply with certain requirements before accessing any biological resource for the purpose of commercial utilization, bio-survey, and bio-utilization, etc.

Here one thing is very significant to clarify that since ss. 3–7 are restrictive in nature and the purpose is to restrict free access, therefore, the rule of interpretation says that in case of any doubt or any text is susceptible of two or alternative meanings, the courts shall give effect to that meaning which is in consonance with the objectives of the Act and in accordance with the intention of the legislature. Therefore, the word 'intimate' in the text of s.7 should be interpreted in the light of the preamble of this Act instead of giving it a literal sense. The literal meaning would defeat the purpose and take things out of the control of the SBB. It can be better understood, if the text of this provision is construed in conjoint reading with the ss.23, 24 of the Act providing for functions and powers of the SBB, respectively. This ambiguity was also raised as a ground of arguments in Divya Pharmacy's case wherein Uttarakhand High Court observed that the text of s.7 can be properly understood only if it is read with ss.23 and 24 which authorizes the SBB to regulate the grant of approval or otherwise requests. Further in ss. 55(2) and 56, the provisions providing for punishment also indicate the authoritative status of the SBB to accord approval instead of working as a mere information recipient agency.

However, the access by local people being involved in the cultivation of such biological resources does not attract the condition of prior intimation to the SBB. Not only this Act but the UNEP and CBD also are aware of the fact that biological wealth is heavily utilized by people and contributes to roughly half of the world's economy (UNEP 1993). Furthermore, *vaids* and *hakims* involved in practising indigenous medicine have also been kept out of the purview of this provision.

Procedure for Obtaining Access u/s 7: (s. 3 r/w r. 14) The procedure and format are the same as explained above in comment of s. 3 of the Act.

23.2.4.6 Duties of the Central and the State Governments

While looking at the title of chapter IX, it indicates that ss. 36 to 40 deals with duties of the Central and State Governments. However, the headings of ss. 38–40 are titled with the prefix 'Power of. . . .'. Therefore, it has to be construed as Duties and Powers of the Central and the State Governments.

Duties of Government:

(1) To develop national strategies, plans, programmes for the conservation and promotion and sustainable use of biological diversity, including identification and monitoring of biological wealth rich areas, promotion of in situ and ex situ, incentives for research, public awareness, and capacity building (s.36[1])
(2) To issue directives to the concerned State Government to take urgent measures to address deteriorating activities and ameliorative measures along with technical and other assistance (s.36[2])
(3) To integrate cross-sectoral plans, programmes, and policies with statutory goals (s.36[3])

(4) For minimizing the adverse effects of proposed or ongoing projects on the biological wealth of an area to conduct environmental impact assessment with the help of public participation (s.36[4] [i])
(5) To regulate the management or control the risks associated with the use and release of LMO resulting from biotechnology that may cause an adverse effect on flora, fauna, and human health (s.36[4][ii])
(6) To respect and protect the knowledge of local people relating to biological wealth as recommended by the NBA. Also to develop registration mechanism of such knowledge at local, state, and national levels along with developing sui generis system for the protection of their interests associated with knowledge of biological wealth (s.36 [5])
(7) To frame the Biological Diversity Rules (s.62);
(8) The State Governments to notify the areas of biodiversity importance as biodiversity heritage sites in consultation with local bodies (s.37).

Powers of the Central Government

1. To notify threatened species in consultation with respective State Government and periodically review the things along with the obligation to monitor and take necessary steps for rehabilitation and preservation (MOEF Notifications of Various States) (s. 38[1])
2. To designate repositories to upkeep different categories of voucher specimen of biological resources and new taxon discovered (s.39 [1], [2] & [3])
3. To exempt certain biological resources normally traded as commodities (s.40).

23.3 Institutional Framework

The aforesaid structural framework can be implemented with the help of institutions. The Act provides for three-tier institutional mechanisms to achieve the objectives stated in the preamble, namely, the NBA, SBBs, and BMCs. To implement the slogan of *Think Globally Act Locally,* this triple-layer mechanism demarcates the domain of these institutions under the control of the NBA.

23.3.1 NBA

The role of the NBA can be elaborated are as under:

1. Frame regulations and guidelines for access to biological wealth and fair and equitable benefit sharing (FEBS) (ss. 18[1], 19 [1] & 20 [1])

2. Grant of approval for activities specified in ss. 3, 4 and 6 (ss. 18[2], 19[2] & 20 [2])
3. To advise the Central Government and State Governments on matters concerning the threefold objectives of the Act and perform functions related thereto (s. 18[3])
4. To oppose the grant of IPR anywhere on any biological wealth of Indian roots on behalf of the Central Government (s. 18[4])
5. To enquire and consult expert committee and stakeholders before the grant of approval on any issue referred to it under the Act and decide on terms and conditions (ss. 19[3] & 20[3])
6. To determine the amount of equitable benefit sharing at the time of sanction in ss. 19, 20 & 21[1] [2] [3])
7. To frame the rules on access to genetic resources and fair and equitable sharing of benefits arising out of utilization (s.64 r/s18 and sub-section 21[4]).

23.3.2 SBBs

For the purpose of decentralization of powers and effective functioning of the institutions, the SBBs have been envisioned under the Act. The role of SBB can be discussed as under:

1. To advise the State Government on matters concerning threefold objectives of the Act and perform functions related thereto (s.23 [a])
2. To regulate access to biological wealth within its territorial jurisdiction by entertaining application filed u/s 7 and performing functions related thereto (s.23 [b][c])
3. To enquire and consult local bodies before granting approval on any issue referred to it under the Act and decide on terms and conditions (s. 24[2])
4. To issue an order to prohibit or restrict any such activity in case that activity is detrimental to the objectives of the Act (s. 24[2]).

23.3.3 BMCs

To give special focus on the third statutory goal of ensuring fair and equitable sharing of benefits arising out of the use of biological wealth and ground-level implementation of the legislative intent, the BMCs have been constituted. The role of BMCs can be discussed as under:

1. To perform functions in pursuance of threefold objectives of the Act (s. 41[1])
2. Documentation of biological wealth and contribution to preservation of habitats, conservation of land races, folk varieties and cultivars, domesticated stocks and breeds of animals, and micro-organisms (s. 41[1])
3. Chronicling of knowledge concerning biological wealth (s. 41[1])

4. Render consultancy to the NBA and SBBs while taking any decision concerning the use of biological wealth within the territorial jurisdiction of the BMC (s. 41 [2])
5. Levy charges by way of collection fees from any person for accessing or collecting any biological resource for commercial purposes from areas under its territorial jurisdiction (s. 41[3]).

The above functions and involvement of BMCs remind the obligation of the contracting parties under Arts. 10 & 11, CBD to devise and adopt traditional cultural practices and measures compatible with the goals of conservation and sustainability. Art. 10 dictates the involvement of local populations to develop and implement remedial steps to protect biological resources against degradation.

23.4 Remedial Framework

No law can realize its objectives unless it is properly implemented and effectively enforced. The provisions concerning implementation by the respective agencies to implement the structural framework have been dealt with in the aforesaid discussion. This part discusses the enforcement under the head of the remedial framework. It addresses deviation, violation, or contradiction to the directives issued and provisions, respectively, by prescribing penalties and punishments. In other words, where the orders, directions, or command of institutions created under the Act are not implemented properly, the role of the court to enforce the provision begins. The courts are authorized to inflict sanctions and commands obedience to the law. It is, in fact, a sanction that infuses life in the law. Without sanction, the law loses its sanctity. Therefore, the sanction is considered as an essential element of law to compel the citizens to obey and respect the law. It is basically a coercive fact binding a person to behave according to the law. The following provisions are remedial and penal in nature:

23.4.1 Appeal

There is a provision of appeal by any aggrieved person against any order or determination of benefit sharing, to the High Court within 30 days from the date of communication to him (s. 52). Sub-section 52-A has been inserted in 2010 as a complementary provision at the time of introducing the National Green Tribunal, 2010. It allows an aggrieved person to file an appeal against any determination of benefit sharing or order of the NBA or the SBB if the determination or order has been passed on or after the commencement of the NGT Act, 2010. The orders passed under this Act by the NBA, SBB, and HC shall be executable in the manner as the decree of civil court is executed (s.53).

23.4.2 Penal Provisions

The proceedings before the NBA are deemed to be judicial proceedings within the meaning of ss. 193 and 228 of IPC. The NBA shall be deemed to be a civil court for the purposes of ss. 195 and 196 of the IPC (Reference to Chap. XXVI of Cr.P.C., 1973 also). The officials of the Central Government, State Government, NBA, or SBBs shall not be liable for any act which is done in good faith or intended to be done under this Act or the Rules and regulations made thereunder (s. 54).

1. The officials of the NBA, SBB shall be deemed to the public servant within the meaning of s.21 of IPC.
2. Any contravention, attempt to contravene or abet the contravention of ss.3, 4, and 6 is punishable for a term which may extend to 5 years or with a fine that may extend to ten lakh rupees or with both. In case, damage exceeds ten lakhs rupees, the fine may be commensurate with the damage caused or with both (s. 55[1]).
3. Any contravention, attempt to contravene or abet the contravention of s. 7 or any order made under s. 24(2), shall be punishable with imprisonment for a term that may extend to 3 years or with fine that may extend to five lakh rupees or with both (s.55[2]).
4. S. 56 provides residuary Cl. of punishment. Where any person contravenes any direction or order issued by the Central Government, the State Government, NBA, SBB for which the Act does not provide for separate punishment, the person can be punished with a fine of up to one lakh rupees and for a second or subsequent offence, fine up to two lakh rupees, and in case of continuous contradiction, an additional fine of up to two lakh rupees every day for continuation of the fault.
5. Where any offence or contravention under the Act is committed by a company, every person who was In-charge at the time of committing that contravention shall be deemed to be guilty of the offence or contravention subject to standard defence Cl. of exercising due diligence to prevent such commission.

23.4.3 Nature of Offences: The Offences Under the Act Are Cognizable and Nonbailable

By cognizable offence, it means the offences are of a serious nature and the police officer can arrest in these matters without a warrant. Similarly, non-bailable offences are also of serious nature. In such offences, the courts have the discretion to decide on the application of bail. In such matters, bail cannot be claimed as a matter of right. The kinds and details of cognizable and non-bailable offences are mentioned in Schedule I of the Code of Criminal Procedure, 1973.

23.5 Conclusion

The foregoing discussion reveals that the Act and the Rules framed thereunder do comply with the obligation of the GoI under CBD. Evaluation of various aspects of this Act in the light of the standards and mandate of CBD reveals that the Act makes comprehensive arrangements for the identification of deteriorating practices, processes, undue exploitation for commercial purposes, inventorization of biological resources, involvement of local-level stakeholders in decision making, conservation of associated traditional knowledge, biotechnology, IPR, promotion of research, development, cooperation between developed and developing nations, and sharing technology, etc. The distinguishing and progressive feature of this Act is the time limit specified for the NBA and SBBs to dispose of the applications filed u/ss. 3, 4, 6, 7, and so on. These measures can certainly contribute to curbing dilatory tactics and unnecessarily discouraging the research fraternity as well as other stakeholders. However, there is an apprehension that these guidelines could have been made more effective by reducing the period of disposal of application from 90 days to a lesser number of days in the digital age. With the help of digital means, the functioning of the statutory authority needs to be improved and less time consuming. The participation of other stakeholders can also be ensured through the digital mechanism to increase the efficient performance of the institutions.

Besides, it is submitted that though the Act is perfectly in synchronization with the CBD, its preamble apparently underscores the threefold objectives verbatim, yet the realization of the objectives depends on its proper and effective implementation. No law can serve society effectively unless it is accepted by the society in the form of its observance of the stakeholder. It must be visible in their conduct, activities, behaviour, and lives. Biological Diversity Act is connected with the lives of not only the present but also future generations. It is an attribute of life and the basis for the survival of almost each and every species. Therefore, the purpose of conservation and sustainable use of biological resources shall remain distant despite the passing of as many as possible number of laws unless the people who are responsible mend their ways to treat our biological wealth. The studies reveal that around 40 percent of the Earth's net primary terrestrial photosynthetic productivity is being consumed, converted, or wasted directly as a result of human activities (Vitousek et al. 1986). There is an urgent need to critically assess the impact of human ventures on biological wealth. The gestures of eyewash, mere lip-service, or framing of law without ground-level implementation would be of no gain. The stakeholders, especially policymakers and pioneers at the international as well as national levels, should rise from their political ideologies and make concerted and unified efforts. Setting the political scores under the pretext of participatory and democratic decisions-making processes in the environmental domain may cost heavily. Ongoing debates on draft EIA Regulations should be taken up seriously and debated on merit. S. 36(4)(i), empowering the Central Government to conduct EIA of the proposed or ongoing activities to evaluate its effects, is in tune with Art. 14 of CBD guidance for EIA and public participation in this exercise in pursuance of Art.

13, providing for public education and awareness. Besides, the Guidelines on Access to Biological Resources and Associated Knowledge and Benefit Sharing Regulations, 2014 have also been placed under revision. There were many ambiguities in the previous Regulations which created many legal disputes, such as Divya Pharmacy v. Union of India (2016) were having their origins in the ambiguity in the legal text. The petitioner attempted vigorously to avail the shelter of the language of s.7 placing him on an advantageous footing, which was against the spirit of the Act as well as CBD.

The court removed this anomaly by applying rule of purposive construction. It rejected the contention of the petitioner to apply literal rule of interpretation for deriving the true meaning of s.7 which says the word ‘intimation’ to be given to SBB. It was further pleaded that the word ‘intimation’ should not be construed in the sense of ‘seeking of prior approval as spelled out u/ss. 3, 4 & 6 of the Act. Had the Court accepted the arguments of the petitioner, it would have resulted in defeating the purpose of the Act, FEBS. While the respondent argued that s.7 should not be construed in isolation. It needs to be interpreted in light of the objectives of the Act and its complementary provision s. 23. The objectives of the Act clearly echoes the pious objectives of ‘fair and equitable benefit sharing’, therefore the literal interpretation has to give way to purposive construction. The wisdom of the Court prevailed illustriously and the Court, while rejecting the plea to apply the literal rule of interpretation, applied the rule of purposive construction which emphasizes adopting the meaning which furthers the purpose of the Act. It also cautioned that ‘*what may seem obvious, may not always be correct*’. Literal interpretation may not always serve the purpose for which the law was passed. Thus, when the courts have to make a choice between ‘a purposive interpretation and a narrow literal interpretation’, that interpretation shall be preferred which shall be helpful in achieving the purpose of the Act. Therefore, in the instant case, purposive interpretation was preferred over literal interpretation, as adhering to the later might have frustrated the objectives of the Act.

The same approach has to be part of the temperament of all stakeholders. Instead of availing of the escape route, the spirit of the law should be respected. Such short-term monetary advantages may undoubtedly result in irreparable harm. The attempt should be, beyond question, to give preference to the objectives of the Act and therefore due weightage should be given at the time of implementation and enforcement of legal provisions. Even at the time of impact assessment of proposed activities, not only the small-term gains but long-term impacts on the constituencies, e.g. present generation, flora and fauna, institutional performance, the national and international image of the country’s legal system, and other sectors should be properly measured. Development based on *capitalistic imperialism* (Rajya Sabha 2002) is a misconceived priority and needs revisit. The trends in the last 50 years show that whenever a conflict between economics and ecology occurs, ecology is pushed back as the pillion rider, and economics is placed in the driving seat.

To sum up, the role of multi-stakeholders covering traders, manufacturers, commercial institutions, indigenous people, and women have been recognized at levels such as at the international level through the CBD, at the national level through the Act and Rules, and at the local level through the Rules of SBB. There is a need to put joint efforts in exercise vigorously and intensively to hand over a better planet to the coming generations, so that posterity may treat us kindly.

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