Chapter 1
Introduction

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Abstract This book provides an overview of the decades-long work of studying, analyzing, and reversing the environmental pressures that threatened India's Chilika Lagoon, the largest brackish-water lagoon in the region, and the second largest in the world. Following the establishment of the Chilika Development Authority (CDA) steps were taken to gather information and devise a restoration plan that benefits the ecosystems of the lagoon, with sensitivity to the needs and livelihoods of local communities. The restoration plan included a major hydrological intervention to re-establish hydrological and salinity regimes, biodiversity, and fish catches, and help protect the livelihood of lagoon-dependent communities. Expert contributors detail the work of analysis, planning and implementation, including extensive coverage of such topics as: implementing Ramsar wise use guidelines; sedimentologic, chemical, and isotopic impacts; hydrodynamics and salinity; runoff and sediment in watersheds; water quality and continued monitoring; bio-optical models for cyclone impact assessment; geomorphology, land use, and sedimentary environments; spatiotemporal assessment of phytoplankton communities; post-restoration scenario for fish and fisheries; and the status of waterbirds, species diversity and migration patterns.

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Located at the land-water interface, coastal wetlands are affected by both land and ocean processes, and function as valuable sources of primary and secondary productivity and biodiversity, which are crucial to support life on our planet. Wetlands are highly productive ecosystems and at the same time, they are highly vulnerable to anthropogenic and natural disturbances (Ramsar Convention 2018). Considering the socioecological importance of wetlands, the international community in 1971 established the Ramsar Convention on Wetlands (Matthews 1993). Under the Convention wetlands include areas that are either permanently or seasonally inundated with water and, depending upon the geomorphology, hydrological regime, and vegetation, they comprise various types such as mangroves, peatlands, marshes, estuaries, rivers, lakes, and flooded forests. Being a transitional ecosystem, they pose many challenges with respect to management, monitoring, and conservation as well as the multitude of stakeholders depending on them for their livelihoods. One such wetland, Chilika Lagoon, the largest brackish water lagoon in Asia, is an extremely important natural asset for the State of Odisha, India. Successful management of Chilika requires not only conserving and preserving the biodiversity of this lagoon and its ecosystem services, but also the livelihoods of the coastal communities (Kumar and Pattnaik 2012). Chilika presents a role model of successful implementation of the Ramsar Convention in which an ecosystem approach has been used for conservation and sustainable management of natural resources.

This book is designed to highlight the theories, past developments, and current state-of-the-art knowledge in management and conservation of the coastal lagoon. Chilika Lagoon has been intensively studied by numerous physical and social scientists for many decades. However, because of the lack of a coherent and comprehensive synthesis of the multi-decadal research on this important environment, the focus of this book is squarely placed on Chilika Lagoon. The book contains 16 chapters covering key topics on geomorphology, ecology, water resources, ecosystem management and restoration pertaining to Chilika Lagoon, as well as making it immensely helpful for the management of similar lagoon ecosystems elsewhere.

The eco-restoration approach which considered ecological, social, and economical inter-connectedness has been described in Chap. 2 "**An overview of the restoration and management of Chilika Lagoon: successful application of the Ramsar wise use guidelines**". The integrated management planning framework for Chilika, and the wise use of natural resources in the context of sustaining the ecological character and ecosystem services of the lagoon have been discussed in detail.

The ecological character of Chilika mostly depends on its hydrological regime which is linked with both natural and anthropogenic factors. Ecological character is therefore an indicator of the overall health of the Chilika ecosystem as it includes all critical components (e.g., bathymetry, hydrology, water quality, biodiversity), processes (e.g., fish recruitment, sedimentation, inlet migration), and ecosystem services (e.g., provisioning, regulating, and cultural). The framework provided for such

characterization under the Ramsar Convention has been discussed in the context of Chilika in Chap. 3 "**Ecological characterization of Chilika: defining strategies and management needs for wise use**" and Chap. 4 "**Ecosystem services: implications for managing Chilika**". From a management perspective, the identification of key ecological characters, processes, and services and threats to the ecological character and ecosystem services have been summarized in detail.

Chilika Lagoon is subjected to many anthropogenic stresses such as siltation, weed infestation, and nutrient loading. To help trace and quantify the anthropologic effects on Chilika Lagoon, Chap. 5 "**Sedimentologic, chemical, and isotopic constraints on the anthropogenic influence on Chilika Lake, India**" presented a comprehensive geochemical dataset acquired during both the dry and monsoon season from the lake. The trends in isotope composition (Hydrogen, Oxygen, Carbon, and Nitrogen) in addition to salinity, Dissolved Inorganic Carbon, and POM were presented which revealed that the mixing of freshwater with seawater mainly controlled the geochemical composition of the lagoon ecosystem. Seasonal and sectoral variability was also observed. The data presented on N-isotope composition is also important for the evaluation of the invasive macrophytes that proliferate along the shores and are seen as a potential environmental hazard, but may actually be effective filters for excess nitrate and nutrient fluxes into the lagoon.

The ecology of Chilika Lagoon entirely depends on salinity which is determined by freshwater inputs and tidal flux. The hydrodynamic circulation is dependent on many physical processes such as wind directions, water currents, and position and cross section of the seawater inlets. Chapter 6 "**Modelling of hydrodynamics and salinity characteristics in Chilika Lagoon**" complemented the findings presented in the previous chapters by shedding light on the hydrodynamic circulation which controlled the geochemical and biological properties of the lagoon. A fully integrated time generalized hydrodynamic model with effects from tide, wind, and freshwater sources and sinks was presented. A shift in key forcings from wind and tide in summer to freshwater influx during monsoon which controlled the hydrodynamic and salinity patterns of the lagoon was observed. The study concluded that the hydrological intervention and restoration measures have facilitated better exchange with the sea resulting in an improvement in salinity distribution and ecology of the lagoon. However, shifting of the inlet(s) and siltation in the dredged channels remain as significant concerns.

Chilika has a vast catchment area of approximate 4406 km^2 which contributes a large sediment load to the lagoon through freshwater discharge from the rivers. This sediment load enriches the lagoon with nutrients and organic matter leading to extensive colonisation of macrophytes. Chapter 7 "**Assessment of runoff and sediment yield from selected watersheds in the Western Catchment of the Chilika Lagoon**" presented a hydrological model to estimate runoff and sediment load in the western catchment which drives siltation and affects the overall water quality of the lagoon. A Soil and Water Assessment Tool (SWAT) model for two river basins in the western catchment was calibrated and validated with the results

showing that rainfall was the main source of runoff which brought a significant amount of eroded sediment into the lagoon. The study concluded that the sediment load was harmful to the sustainability of the lagoon and needed to be stopped at the source, which is the catchment itself.

Chilika is a turbid water lagoon due to a high amount of suspended sediments in the water column which determines the quantity and quality of the light available to phytoplankton for primary production. Chapter 8 "**Long-term analysis of water quality in Chilika Lagoon and application of bio-optical models for cyclone impact assessment**" examined the long-term water quality of the lagoon in terms of total suspended sediment and chlorophyll-a (a proxy for phytoplankton abundance) using NASA's MODIS satellite data. The study also presented the differential impact of the recent anniversary super cyclones, Phailin and Hudhud on the lagoon. Analysis of a 14-year dataset revealed that the seasonal variability of Total Suspended Solids was dominant in all the three sectors of the lagoon compared to inter-annual variability. The study concluded that many factors including the location of the landfall, intensity, trajectory, and speed of the cyclone played a role in determining the outcome (high turbidity versus high phytoplankton) for the lagoon.

Systematic and comprehensive monitoring of water quality constitutes an important step in assessing the ecological health of Chilika Lagoon. Chapter 9 "**Spatio-temporal variation in physicochemical parameters of water in the Chilika lagoon**" discussed the long-term water quality variability using a large dataset collected between 1999 and 2015 from 30 permanent stations. The chapter presents an overview of seasonal and sectoral variation in physicochemical factors such as salinity, nutrients, dissolved oxygen in relation to major physical processes such as mixing of freshwater with seawater, rainfall patterns, river water discharge, and tidal influx from the Bay of Bengal. The outcomes were also compared with thresholds prescribed by Central Pollution Control Board, New Delhi for water quality guidelines set for the propagation of wildlife and fishery.

The Land Use/Land Cover (LULC) changes in Chilika affect many physical and biological processess in the lagoon through change in salinity, increased nutrient inputs and weed infestation. Remote sensing and GIS are important tools to document changes in geomorphic and anthropogenic processes. Chapter 10 "**Geomorphology, land use/land cover and sedimentary environments of the Chilika basin**" presented the outcomes of geomorphic studies in and around Chilika from 1980 to 2015 using remote sensing data. LULC mapping was carried out to examine the anthropogenic changes surrounding the lagoon which could be playing a role in degrading the water quality. The study concluded that the lagoon is facing a significant problem of siltation mainly due to improper utilization of LULC. Agriculture plantations and barren lands are more vulnerable due to the impact of urbanization, such as engineering construction, settlements, and transport. Changes in the island landforms within the lagoon are mainly due to the hydrodynamic circulation.

The productivity of the Chilika lagoon, thus, the entire trophic food chain relies on the phytoplankton communities, the primary producers of the system. The spatiotemporal distribution of phytoplankton communities provides a vital clue regarding the trophic status of the system and are used as bioindicators for several

biological processes such as eutrophication and harmful algal blooms. Chapter 11 "**Spatiotemporal assessment of phytoplankton communities in the Chilika lagoon**" provided a detailed assessment of group-wise inventory of the phytoplankton species composition and new records from Chilika based on surveys carried out between 2000 and 2014. The impact of the very severe cyclonic storm '*Phailin'* on the phytoplankton communities is also elaborated. This chapter also provided an insight on major environmental factors that shape the phytoplankton community in Chilika lagoon. The need to further study the diversity of small-size phytoplankton (nano and picophytoplankton) through DNA sequencing is highlighted for a complete understanding of the phytoplankton communities of the lagoon.

Chilika Lagoon has experienced ecological degradation during the 1990s due to the natural closure of the seawater inlet by siltation. This led to a dramatic decrease in the biotic diversity of the lagoon, including the species used for fisheries. In September 2000, the lagoon was restored through the opening of a new mouth for entry of seawater from the Bay of Bengal. This hydrological intervention resulted in a spectacular enhancement in fishery species diversity and catches during the post-restoration period (2000–2004). Chapter 12 "**Fish and fisheries of Chilika Lake: post-restoration scenario**" provided detailed information on the changes in fish diversity before and after the hydrological intervention. The latest inventory on fish and shellfish fauna diversity, their habitat, and conservation status have been provided. In addition, the biology and ecology of commercially important fishes, management challenges, and recommendations for sustainable management of fishery resources in Chilika Lagoon have been discussed.

The bird diversity of Chilika is well recognized for providing several ecosystem services and is considered a key component of the biota along with fisheries. Assessment of the bird diversity and population status have been systematically monitored by the Bombay Natural History Society (BNHS) since 2000. Chapter 13 "**Avifauna of Chilika, Odisha: assessment of spatial and temporal Changes**" provided an overview of the population status of waterbirds, their migration pattern, and species diversity, based on the monitoring studies carried out between 2000 and 2014. The study has highlighted the importance of the Nalabana Bird Sanctuary in providing ideal feeding, resting, and breeding ground for several exotic bird species. Issues related to habitat management such as invasion by grasses on islands, loss of mudflats, and increased human interference have been highlighted to be considered in wetland management planning.

Benthic macro-and meiofauna play a crucial role in the decomposition of organic matter which is accumulated into sediments. The benthic fauna, thus, plays an important role in recycling the nutrients and drive the nutrient cycling leading to the flow of energy in the trophic food chain in Chilika. The species composition of benthic macro- and meiofauna also provides a bioindicator to track natural and anthropogenic disturbances. The benthic fauna also provides a rich source of food for many species of birds and fish. Chapter 14 "**Biodiversity of benthic fauna in Chilika lagoon**" summarized the latest information available on the benthic fauna based on the monitoring survey carried out between 2014 and 2017. The chapter also highlighted the need for conducting long-term monitoring to understand the impact

of fishing, continuous dredging, oil pollution and sewage discharge on benthic communities. The changes induced by these anthropogenic activities would impact the fishery and bird resources of Chilika lagoon and eventually the livelihood of coastal communities.

Microbial ecology of Chilika lagoon, especially with reference to bacterial and archaeal communities, is an understudied area. Despite the fact that microbial communities present in sediments and the water column play a crucial role in the biogeochemical cycling of nutrients, not many studies are available on this subject. Chapter 15 "**Microbial ecology of Chilika lagoon**" summarized the microbial ecological studies available from Chilika and discussed in detail the culture-based and culture-independent approaches. Recent developments in microbial ecology due to high-throughput DNA sequencing and their application in studying the structure and function of microbial communities through metagenomics have been discussed in detail. The role of different biotic and abiotic drivers in structuring the sediment microbial communities have been highlighted.

Macrophytes in a wetland system provide a range of ecosystem services such as sheltering grounds for many faunal communities from their predators, as well as breeding and foraging ground for many ecologically important species of birds, finfish and shellfish. In addition, they play a crucial role in water and sediment biogeochemistry leading to the supply of organic matter into the sediments and water column. Chilika lagoon is a macrophyte dominated system which supports a diverse macrophyte community due to a variety of salinity and nutrient regimes. Chapter 16 "**Survey, characterization, ecology, and management of macrophytes in Chilika lagoon**" described changes in macrophyte diversity due to post-hydrological intervention. Based on the ground survey carried out on Chilika, 748 species of angiosperm were documented. The data on the spread of seagrasses, invasive weeds like *Phragmites karka* along with management recommendations have been discussed. The ecology of macrophytes in relation to water quality parameters have been presented.

The content of this book summarizes the progress that has been made so far by the scientific community studying the lagoon. The methods, models, and analysis synthesized in this book will hopefully address some of the existing challenges in monitoring geomorphic, geochemical, biological properties, water quality, analyzing their interrelationship, and quantifying their impact on other biota such as seagrasses and benthic algae in Chilika Lagoon.

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