Wetlands: Ecology, Conservation and Management 6

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Ecology, Conservation, and Restoration of Chilika Lagoon, India

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Wetlands: Ecology, Conservation and Management

Volume 6

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The recognition that wetlands provide many values for people and are important foci for conservation worldwide has led to an increasing amount of research and management activity. This has resulted in an increased demand for high quality publications that outline both the value of wetlands and the many management steps necessary to ensure that they are maintained and even restored. Recent research and management activities in support of conservation and sustainable development provide a strong basis for the book series. The series presents current analyses of the many problems afflicting wetlands as well as assessments of their conservation status. Current research is described by leading academics and scientists from the biological and social sciences. Leading practitioners and managers provide analyses based on their vast experience.

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Foreword

Wetlands are in deep trouble worldwide. Despite the many and hugely important benefits they provide to people, for centuries, wetlands have been drained and otherwise converted to other land uses, and the loss of wetlands continues largely unabated.[1] We also know that deterioration in the state (ecological character) of our remaining wetlands, including designated Ramsar sites (Wetlands of International Importance), is becoming increasingly widespread.[2]

The reasons behind this continuing loss and deterioration of wetlands are complex, and frequently, there are multiple different, but interrelated, pressures leading to this situation.[3] These often involve inter alia conversion for agriculture and urbanization, pollution, upstream water management actions leading to reduced water and sediment flows, the spread of invasive species, overexploitation of natural resources, and changes in climate. The consequence is often a loss of livelihoods for the local communities who depend on wetlands for their health and well-being.

In this very difficult environment for wetlands, is it possible to reverse their continuing degradation and restore their ecological character? Although hugely challenging, from the evidence provided in this important book, the answer is, at least for Chilika Lagoon, a resounding "yes"! It can and has been done.

So, how has this been achieved for Chilika Lagoon, and by whom? At the time of its designation as one of India's first Ramsar sites in 1981, the Lake was already

[1]Davidson 2014. How much wetland has the world lost? Long-term and recent trends in global wetland area. *Marine and Freshwater Research* 65(10): 934–941.; Darrah et al. 2019. Improvements to the Wetland Extent Trends (WET) index as a tool for monitoring natural and human-made wetlands. *Ecological Indicators* 99, 294–298.

[2]Davidson et al. 2020. Trends in the ecological character status of wetlands reported to the Ramsar Convention. *Marine and Freshwater Research* 71(1): 127–138.; McInnes et al. in press. Citizen science; global assessment; ecological character; wetland status and trends. *Wetlands*

[3]Ramsar Convention Secretariat 2018. Global Wetland Outlook. State of the world's wetlands and their services to people; McInnes et al. in press. Citizen science; global assessment; ecological character; wetland status and trends. *Wetlands*

recognized as being degraded, and that degradation continued in the following decade. It was national and regional government recognition of this, leading to the establishment of the Chilika Development Authority (CDA) in 1991 which has provided the "authorizing environment" for all the subsequent on-the-ground information gathering and action. Scientific research and modeling, understanding ecosystem service values delivered by the Lagoon, and engaging with multiple sectors affecting the Lagoon and with local communities to better understand their needs and livelihoods have all contributed to informing appropriate actions to turn the state of the Lagoon round to the benefit of multiple stakeholders.

The Chilika Lagoon process also provides an exemplar of how a Ramsar Contracting Party can utilize and benefit from all the available mechanisms under the Ramsar Convention on Wetlands and through these to comply with the Convention's wise use provisions. By placing Chilika Lagoon on the Convention's "Montreux Record," the government of India drew international attention to the plight of the lagoon. Following huge efforts to restore the lagoon, "Ramsar Advisory Mission" (RAM) visited in 2001 to review the management actions undertaken and concluded that in view of the achievements, the Lagoon should be removed from the Montreux Record – this was done in 2002. This was accompanied by an ongoing commitment from the Government of India and the CDA to continue to develop and implement an overall management planning process for the Ramsar site, which has now been developed and implemented.

The 2001 Ramsar Advisory Mission (RAM) also recommended that the Convention should consider using Chilika as an exemplary good practice case study of the application of the various Ramsar guidelines, and the use of the Convention's tools and approaches, to address complex site and catchment management issues. In recognition of their successful restoration and wise use efforts for Chilika Lagoon, the Chilika Development Authority received international recognition for their work through their receipt of the Ramsar Wetland Conservation Award and Evian Special Prize in 2002, on the occasion of the 8th Ramsar Conference of the Contracting Parties (COP8, Valencia, Spain).

This important new book provides a wealth of information about Chilika Lagoon as the exemplary good practice case study of the application of the various Ramsar guidelines, and the use of the Convention's tools and approaches, to address complex site and catchment management issues called for by the 2001 RAM.

This book is absolutely essential reading for all of us around the world striving to manage and restore our degrading wetlands. Read the book and be encouraged and excited by it. Can you achieve restoration and wise use of the world's important

wetlands? The Chilika Lagoon story says “yes, you can”! Be inspired by this book – and never again say that it is not possible to turn around the fate of our wetlands, for the great benefit of so many people.

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March 2019

Preface

Coastal lagoons have immense ecological, economical, and social values. These are among the most productive and dynamic ecosystems as they are positioned at the interface between rivers and sea. The Chilika Lagoon, the largest brackish water lagoon in Asia, is located along the eastern coast of India in the state of Odisha. The lagoon provides a range of ecosystem services to the coastal communities. Chilika Lagoon has been considered as a wetland of international importance and has been designated as a "Ramsar site." At the same time, the lagoon is exposed to many natural and anthropogenic pressures such as siltation, weed infestation, illegal aquaculture, as well as cyclonic storms. In 1991, the lagoon was included in the "Montreux Record," a list of threatened "Ramsar sites." Realizing the problems of Chilika Lagoon, the Chilika Development Authority (CDA) adapted an ecosystem restoration approach to prevent the degradation of the lagoon. In the year 2000, CDA performed a major hydrological intervention in the form of opening a new channel between the lagoon and the sea which helped to improve the salinity levels, biodiversity, fish catches, and livelihood of dependent communities. Chilika was removed from the "Montreux Record" in 2001, and the restoration effort was recognized with the prestigious "Ramsar Award" to CDA in 2002.

Sustainable management of Chilika Lagoon is crucial not only for maintaining the rich biodiversity and productivity but also for the wise use of common resources by the communities. Management of Chilika Lagoon needs an interdisciplinary approach to effectively use the information available on different aspects of wetland ecology. The recent recognition of wetlands in the context of their ecosystem services has promoted worldwide conservation efforts with research on all aspects of wetland ecology, biodiversity, hydrology, and conservation. This has resulted in an increasing demand for successful case studies to be conducted on model wetlands such as "Chilika" where research proved to be a vital element in sustainable management and conservation of the lagoon.

Recent research and innovative management practices for the conservation of the Chilika Lagoon have provided a strong foundation for this book. A book addressing all major aspects of wetland ecology including conservation and governance issues must be made available to meet the needs of researchers, wetland managers, and

students. This book will serve as an invaluable resource to aid research on ongoing studies in Chilika Lagoon. The book also identifies existing knowledge gaps for further research and technological developments in wetland studies. The book will also be of interest to those wetland managers who are working in similar coastal lagoon ecosystems around the world where lessons learned from Chilika Lagoon could be applicable for sustainable management and conservation purposes.

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About This Book

This book is based on the original contribution of leading scientists and experts who have worked on Chilika Lagoon for several decades. It covers issues pertaining to the management, governance, and restoration of the lagoon ecosystem, ecosystem services, and lagoon-specific research topics on hydrodynamic modeling, catchment modeling, water quality, sediment dynamics, and spatial and temporal trends in biodiversity (fisheries, avifauna, benthic fauna, phytoplankton, microbial communities, and macrophytes). The book is a significant contribution to research in the increasingly important discipline of wetland management and their conservation using Chilika Lagoon as a case study.

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About the Editors

C. Max Finlayson is an internationally renowned wetland ecologist with extensive experience internationally in water pollution, agricultural impacts, invasive species, climate change, and human well-being and wetlands. He has participated in global assessments such as those conducted by the Intergovernmental Panel on Climate Change, the Millennium Ecosystem Assessment, and the Global Environment Outlook 4 & 5 (UNEP). Since the early 1990s, he has been a technical adviser to the Ramsar Convention on Wetlands and has written extensively on wetland ecology and management. He has also been actively involved in environmental NGOs and from 2002 to 2007 was president of the governing council of global NGO Wetlands International. He has contributed to over 450 journal articles, reports, guidelines, proceedings, and book chapters on wetland ecology and management and to the development of concepts and methods for wetland inventory, assessment, and monitoring and undertaken many site-based assessments in many countries. He is the Editor-in-Chief of the journal *Marine and Freshwater Research* published by CSIRO Publishing and of the book series *Wetland, Ecology, Conservation and Management* published by Springer.

Gurdeep Rastogi is working as a Senior Scientist at the Wetland Research and Training Centre (WRTC) of the Chilika Development Authority (CDA). He has received his PhD in the area of Environmental Microbiology from the National Centre for Cell Sciences, Pune, in the year 2006. He has completed his postdoctoral research at the South Dakota School of Mines & Technology and the University of California, Davis, USA. He is currently heading the molecular ecological research at WRTC, a nodal lab of CDA which has been entrusted with the responsibility of managing the Chilika Lake by the Odisha State Government. His research area is focussed on understanding the microbial biogeography and functions in coastal systems with special emphasis on bacteria, archaea, and phytoplankton. Over the past 15 years, he has published more than 40 papers in peer-reviewed international journals which have been well cited by the scientific communities, worldwide. He is an active reviewer for many international journal published by Springer and Elsevier.

Deepak R. Mishra is a Professor of Geography at the University of Georgia, Athens. His research interests are mainly in the area of remote sensing and satellite image processing as applied to inland and coastal environments. His specific interests are water quality, wetlands biophysical characteristics including gross primary productivity, carbon sequestration potential, application of big data in environmental informatics, and cyber-physical systems research. He completed his PhD in Natural Resources from the University of Nebraska, Lincoln. He has published numerous papers in various high-impact international journals and book chapters, presented his research in many national and international meetings, edited special issues and books, and received external grants from various federal agencies. He currently serves on the editorial board of *GIScience & Remote Sensing*. He is an associate editor of the *ISPRS Journal of Photogrammetry and Remote Sensing* and a senior associate editor of *Remote Sensing* and coeditor of *Southeastern Geographer*.

Ajit K. Pattnaik as the former chief executive of Chilika Development Authority, headed the most successful project of restoration and sustainable management of Chilika Lake for 16 years. He completed his PhD in the "Characterization of Phytodiversity of Chilika Lake" from Utkal University, Bhubaneswar. Chilika was removed from the Montreux Record in 2002, due to the successful ecological restoration. He has 37 years of varied professional experience in the management and restoration of coastal ecosystems, climate change, and disaster management. He has extensive experience in project formulation, planning, management, wetland restoration, ecotourism, and water and community development projects. Presently, he is a consultant to the World Bank and UNDP and holds the position of the vice president of Wetlands International South Asia. He is a member of several international and national scientific and technical committees and has published over 100 scientific articles. He is also member of the expert advisory panel of journal *Lakes & Reservoirs: Science, Policy and Management for Sustainable Use* published by Wiley.

Chapter 1
Introduction

C. Max Finlayson, Gurdeep Rastogi, Deepak R. Mishra, and Ajit K. Pattnaik

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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Keywords Chilika Lagoon · Ramsar Site · Wetlands · Sustainable management · Climate change

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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Chapter 2
An Overview of the Restoration and Management of Chilika Lagoon: Successful Application of the Ramsar Wise Use Guidelines

C. Max Finlayson

Abstract Lake Chilika was listed as a Ramsar site in 1981 and after a period of ongoing degradation was placed on a register of sites (The Montreux Record of the Ramsar Convention), that are in need of further management and restoration. Following a committed management effort through the Chilika Development Authority the site was restored and an active wise use program implemented. These steps were sufficient for the site to be removed from the Record in November 2002. The management effort received international recognition and the Lake is now seen as an example of how to apply the guidance provided by the Convention to ensure the maintenance of the ecological character of a Ramsar site. The history of the application of the Convention to Lake Chilika is described here in recognition of the ongoing management efforts, and as an example for other Ramsar site managers.

Keywords Wetland · Lagoon · Ecological character · Ramsar Convention

2.1 Introduction

The Indian Government acceded to the Ramsar Convention on 1 October 1981 with the Convention formally coming into force some 4 months later on 2 February 1982 with the Ministry of Environment and Forests (MOEF) Government of India being the Administrative Authority for national implementation, including for meeting the requirements to nominate at least one wetland as internationally important (known as Ramsar Sites) and to make wise use of all wetlands. MOEF listed six wetlands as internationally important, including Lake Chilika (Fig. 2.1) which is located in

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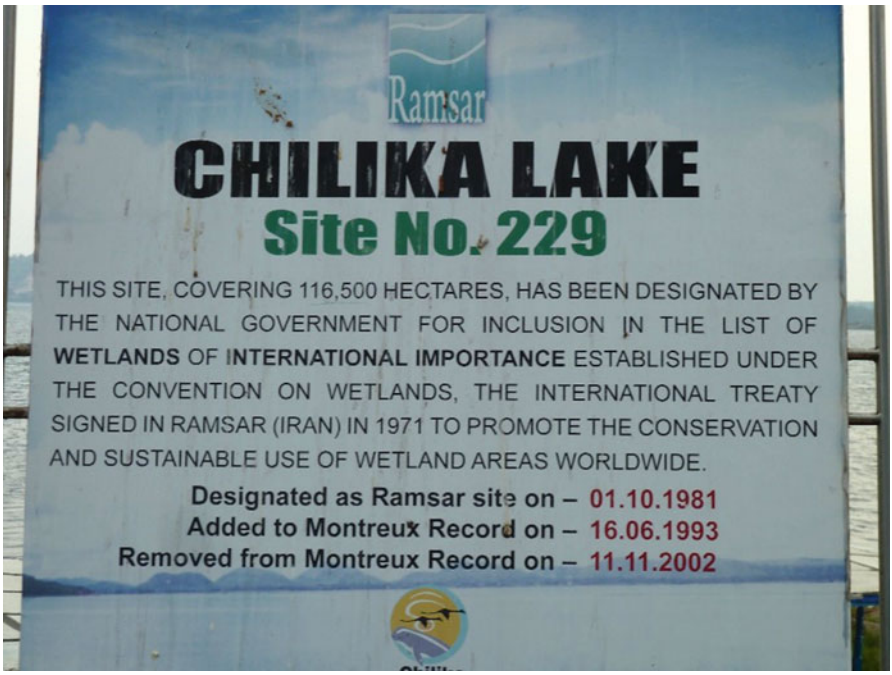

Fig. 2.1 Sign commemorating the designation of Lake Chilika as a Ramsar site in late 1981. (Photograph © CM Finlayson)

Odisha State in eastern India and covers 116,500 ha (Fig. 2.2). The importance of the Lake as a Ramsar site was based initially on four of the criteria used by the Convention at the time (Table 2.1). With the addition of further criteria and the collection of further information two more were applied in May 2001. The most recent version of the Ramsar Information Sheet that was used to describe the ecological character of Lake Chilika is lodged with the Secretariat of the Convention and is accessible through the Ramsar Site Information Service (https://rsis.ramsar.org/RISapp/files/RISrep/IN229RIS.pdf). The Information Sheet was provided initially in 1982 and updated in 2001; a further update is now overdue. Further information on the ecology and management of the Lake has been collated and summarised by Kumar and Pattnaik (2012) in support of the development of an integrated management planning framework for the Lake.

The Ramsar Information Sheet highlights the importance of Lake Chilika for its biodiversity and for the economic importance it has for local people. It is a biodiversity hotspot and supports a valuable fishery resource for more than 0.2 million people. The biodiversity includes over a million migratory waterbirds, including shorebirds (waders); more than 400 invertebrate species; and an assemblage of marine, brackish and freshwater species, as well as several rare, endangered and

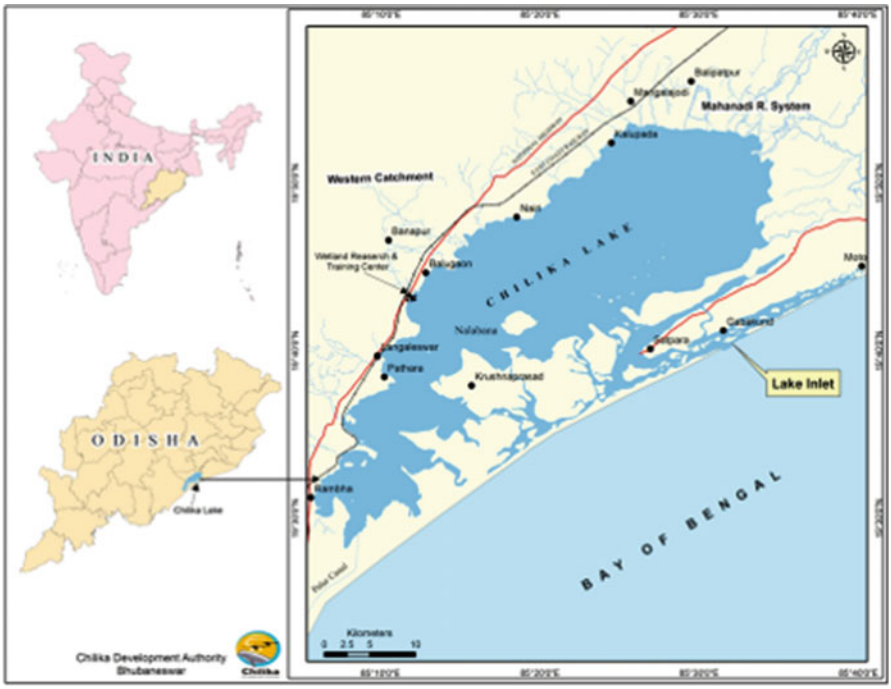

Fig. 2.2 Location of Lake Chilika along the eastern coastline of Odisha State, India (Chilika Development Authority)

Table 2.1 Criteria used to list Lake Chilika as internationally important, initially in 1982 and as updated in 2001

1 February 1982		
Criterion	1	Contains a representative, rare, or unique example of a natural or near-natural wetland type found within the appropriate biogeographic region
	2	Supports vulnerable, endangered, or critically endangered species or threatened ecological communities
	3	Supports populations of plant and/or animal species important for maintaining the biological diversity of a particular biogeographic region
	5	Regularly supports 20,000 or more waterbirds
15 May 2001		
Criterion	7	Supports a significant proportion of indigenous fish subspecies, species or families, life-history stages, species interactions and/or populations that are representative of wetland benefits and/or values and thereby contributes to global biological diversity
	8	Important source of food for fishes, spawning ground, nursery and/or migration path on which fish stocks, either within the wetland or elsewhere, depend

threatened species. Detailed species inventories are available, for the micro- and macrophytic vegetation, as well as for invertebrate and vertebrate animals although the knowledge about the biodiversity contains many gaps (see descriptions and tabulation in Kumar and Pattnaik 2012).

Chilika is the largest coastal lagoon on the east coast of India and considered to be the lifeline of the state of Odisha. It is a highly complex ecosystem and is influenced by a diverse range of social and economic factors within its catchment and also within the coastal zone. Not unexpectedly therefore, the management of Chilika is also complex – all the more so given the dual purpose of ensuring the rich biodiversity is conserved as well as supporting the sustainable livelihoods for the communities dependant on the wetland resources. Given this complexity the management is not prescriptive, but rather has been adaptive and developed in order to enable managers to respond to changing needs and information, especially concerning the linkages between the biodiversity and the people. The long-term objective of the management planning is the conservation and wise use of the Lake, integrating management of the catchments and coastal zones to ensure the ecological security and livelihood improvement for local communities (Kumar and Pattnaik 2012).

Unfortunately, the Lake which had been undergoing adverse changes to its ecological character since the 1950s prior to being nominated as a Ramsar site continued to degrade under the influence of multiple pressures (Fig. 2.3). These included increased sediment loads from the catchment which infilled parts of the lake, particularly in the north-western area, and led to reduced connectivity with the ocean, which in turn, resulted in changes in the water salinity. Invasive weeds, including *Eichhornia crassipes*, *Azolla pinnata*, and *Potamogeton pectinatus*, also established and a process of terrestrialisation was underway with a reduction in the volume and depth of the water. The introduction and expansion of shrimp ponds added further pressure on the ecological character of the lagoon ecology and also ultimately led to significant disruption of the community institutions that had traditionally managed the fisheries in a sustainable manner. These changes have been outlined by Kumar and Pattnaik (2012) and have been the subject of many discussions, including technical workshops, community consultations and political dialogue. Information from these activities has also been used to develop public awareness and encourage knowledge exchange about the Lake and its management.

These changes were leading to many adverse consequences for the biodiversity in the lagoon as well as having a large impact on the livelihoods of the communities, especially those dependent on fishing. In the terms of the Ramsar Convention the Lake was recognised as undergoing an adverse change in ecological character and needed urgent managerial intervention. As the Lake provided an important setting for human wellbeing and livelihoods (*sensu* Horwitz and Finlayson 2011) with a large population of local people being dependent on its resources, the situation had a critical human dimension that if not effectively addressed could have had dire outcomes. This situation formed the background for the inclusion on 16 June 1993

Fig. 2.3 Pressures on the ecological character of Lake Chilika: invasive weeds; extensive fisheries; and increased tourism. (Photographs © CM Finlayson)

of Chilika into the Montreux Record of the Ramsar Convention at the request MOEF. This is a voluntary record for listing sites that have or are undergoing adverse human-induced change in ecological character (Finlayson 1996) where ecological character is defined as "the combination of the ecosystem components, processes and benefits/services that characterize a wetland at a given point in time".

In this paper the managerial responses that have occurred since the Lake was placed on the Montreux Record in June 1993 are assessed, including in particular how the Chilika Development Authority and the Government of India have responded to the recommendations that followed. In this respect the Lake is presented as an example of how the managers have adhered to the requirements under the Convention to manage the Lake and restore its ecological character. This is seen as a major achievement given the size and complexity of the site and the prevailing socio-economic conditions. It also provides a case study for other countries seeking to make full use of the procedures and guidance available through the Convention.

2.2 The Chilika Development Authority

In response to the deterioration of the ecological character of the Lake the Government of Odisha created an institution i.e. the Chilika Development Authority (CDA) in 1991 to lead an urgently needed and complex ecosystem restoration program. Financial support for the CDA came from the State Government and also from the Ministry of Environment and Forests, Government of India. The principal objectives of the CDA are:

(i) to protect the lake ecosystem and its genetic biodiversity;
(ii) to survey, plan and prepare a proposal for integrated resource management in and around the lake;
(iii) to undertake multi-dimensional and multi-disciplinary development activities; and
(iv) to cooperate and collaborate with other institutions for development of the lake.

The establishment of the CDA was an important step and heralded a successful and concerted effort that over the past 25 years has seen the situation in the Lake turned around, with many beneficial changes for people and for the biodiversity that characterises the Lake.

The CDA has initiated a number of major management programmes including:

(i) rectification of some of the land use and land cover problems in the degraded catchments;
(ii) an intensive hydrobiological monitoring effort;
(iii) hydrological intervention based on the outcome of numerical modelling to restore the hydrology and salinity regime;
(iv) the sustainable development of fisheries;
(v) wildlife conservation and the development of ecotourism;
(vi) extensive community participation and development; and
(vii) capacity building at various levels.

In 2000, after detailed investigations, rigorous modelling, and consultation a major hydrological intervention was undertaken with the opening of a new mouth to the Bay of Bengal (Fig. 2.4). This was designed to help restore the salinity regime, facilitate auto-recruitment breeding and migration to enhance the fish catch, reduce the area under invasive species and improve the overall water quality. The ecological recovery that occurred resulted in significant improvements in the livelihoods of the communities dependent on the Lake. In response to these improvements the Government of India requested the Secretariat of the Ramsar Convention to consider removing Chilika from the Montreux Record. This occurred in 2002 following the submission of a Montreux Record Questionnaire to the Ramsar Secretariat (on 30 April 2001) and acceptance of the recommendations of a Ramsar Advisory Mission to the Lake (Finlayson et al. 2001).

The restoration effort was recognized with The Ramsar Wetland Conservation Award and Evian Special Prize being presented to the CDA in 2002. The citation for