Chapter 4
Ecosystem Services: Implications for Managing Chilika

Ritesh Kumar, Ajit K. Pattnaik, and C. Max Finlayson

Abstract An ecosystem services-led management of Chilika encourages a progression from a siloed approach to conservation of species and habitats to explicit consideration of benefits humans derive from these ecosystems, enabling anticipation of a wide range of consequences that may result from different management regimes, and provide tools for identifying, negotiating, avoiding, and managing potential negative tradeoffs. Wetland management would stand to benefit by explicit recognition of intrinsic, instrumental and relational values of the Ramsar Site and contributions to human well-being at multiple scales and sectors. While the investments into the restoration of Chilika has high economic efficiency, the distributional aspects of benefit sharing need to be addressed through interventions such as reducing fishing effort, increasing value realization through strategies as product differentiation, and enhancing participation of fishers in the higher segments of the value chain. The financing arrangements for wetlands management in place are not linked with the costs of ecosystem services provision, especially the maintenance of critical ecosystem processes and functions. Institutional arrangements for the management of provisioning services and select cultural services (mainly tourism) have emerged over a period of time, however, there is a relative vacuum when it comes to the management of regulating services (such as water regime moderation, nutrient cycling, carbon sequestration and others). Much of management effectiveness is dependent on the extent to which the institutions responsible for managing various sectoral programmes (such as climate change, rural development, water and sanitation, disaster risk reduction) take into account the multiple ecosystem services of

R. Kumar (✉)
Wetlands International South Asia, New Delhi, India
e-mail: ritesh.kumar@wi-sa.org

A. K. Pattnaik
Chilika Development Authority, Bhubaneswar, Odisha, India

C. M. Finlayson
Institute for Land Water and Society, Charles Sturt University, Albury, NSW, Australia

IHE Delft, Institute for Water Education, Delft, The Netherlands

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Chilika and the implication of development programmes for sustained provision of such services. A research and monitoring framework for measuring and managing ecosystem services of Chilika needs to be based on an understanding of how the multiple services are generated by coupled social-ecological systems, their interactions and interlinkages with human well-being, and how values for ecosystem services feed into stakeholder behaviour and attitudes towards wetlands conservation and wise-use.

Keywords Ecological character · Ecosystem services · Multiple values · Governance · Distributional equity · Economic efficiency

4.1 Introduction

The management of wetlands designated as Wetlands of International Importance (Ramsar Sites) strives to achieve 'wise use' by ensuring compatibility of human use of the ecosystem with the goal of maintaining ecological character (Pritchard 2016). Wetlands wise use remains to date one of the longest established examples amongst intergovernmental processes of ecosystem approaches for conservation and sustainable development of natural resources (Finlayson et al. 2011). The approach recognises the essential linkages that exist between people and sustainable development of wetlands and encourages community engagement and transparency in negotiating trade-offs and determining equitable outcomes for conservation (Finlayson 2012). In 2005, the Contracting Parties to the Ramsar Convention adopted a revised definition of wise use to include the goal of maintenance of ecosystem services alongwith maintenance of ecosystem components and processes. This revision conceptually conveys an increasing appreciation of the coupling between nature and society (Schoon and van der Leeuw 2015), and the fact that ecosystem services are not generated by ecosystems alone, but by social-ecological systems of which humans are endogeneous (Levin et al. 2013; Reyers et al. 2013).

Ecological restoration of Chilika has been noted for the use of community-led adaptive management approach towards the wise use of wetland (Finlayson et al. 2001; Ghosh et al. 2006). The Chilika Development Authority (CDA), instituted in 1991 by Government of Odisha as the nodal agency for the management of Chilika has an aim of 'conserving lagoon ecology and bringing an all-round development in and around the lagoon' (www.chilika.com). The management plans which have guided CDA's functioning over the years have sought to seek a balance between maintaining species habitats and human use of the lagoon for fisheries and tourism. Yet, setting of management priorities has not been consciously based on an explicit recognition of multiple ecosystem services, and their underpinning ecosystem components and processes, as well as drivers of change. The aim of this paper is to synthesize the available knowledge on Chilika ecosystem services, and map implications for managing the Ramsar site.

The paper is structured in eight sections. We begin by outlining our analytical approach for unpacking ecosystem services from the lens of wetlands management. The economic values of select ecosystem services benefits are discussed next, followed by an assessment of the economic efficiency of investment in wetland restoration, and issues related to distributional equity. Valuation of ecosystem functions underpinning ecosystem services through the case of fisheries is presented thereafter. The final section maps the relevance of ecosystem services information with management and governance, using the analytical approach as the framework of enquiry. Barring the second section, the paper largely delves on economic values of ecosystem services benefits, while recognizing that such values form only a part of multiple values of wetlands, instrumental as well as relational, and a discussion based on the full range of values can form a more meaningful basis of analysis (Kumar et al. 2017; Pascual et al. 2017).

4.2 Analytical Approach

The Ramsar Convention defines wetlands wise use as 'the maintenance of their ecological character, achieved through the implementation of ecosystem approaches, within the context of sustainable development'. Ecological character is 'the combination of the ecosystem components, processes and benefits/services that characterise the wetland at any given point in time'. With the inclusion of ecosystem services within the definition of ecological character, a formal bridging of natural and social science notions of wetlands has been made (Braat and de Groot 2012), thus further embellishing the case for their integrated management on the basis of the full range of ecosystem services and biodiversity values while framing management objectives (Parrott and Quinn 2016; Zsuffa et al. 2014).

Since the revision of the definition of ecological character (Conference of Parties (CoP) Resolution IX.1), several guidelines have been adopted at the Ramsar CoP meetings to support the incorporation of ecosystem services in core inventory and assessment fields (Resolutions IX.1 Annex E, X.15, XIII.13), reporting change in ecological character (Resolution X.16), management effectiveness evaluation (Resolution XII.15); and sectoral guidance such as that on water management (Resolution IX.1 Annex C, X.19), poverty reduction (Resolutions IX.14, X.28, XI.13), human health (Resolutions X.23, XI.12), environment impact assessments (Resolution X.17), climate change (Resolutions X.24, XI.14, XII.11, XIII.12, XIII.14), urbanization (Resolutions X.27, XI.11, XII.10, XIII.16), disaster risk reduction (Resolution XII.13), tourism (Resolution XI.7), and sustainable development (Resolution XI.21). No attempt is made to summarize these guidelines here. Yet, it suffices to say that none of these guidelines individually or collectively represent a consistent framing of a process, or lines of enquiry to enable systematic assessment of ecosystem services in wetlands management planning and decision-making processes.

While the generation of knowledge about ecosystem services is a useful starting point, the knowledge alone may be insufficient for incorporating them into decision-making (Primmer et al. 2015). Rather a grasp of decision-making processes of stakeholders, integration of research into institutional design and policy implementation; and policy interventions designed for performance evaluation and improvement over time may be required in an iterative and adaptive framework (Daily et al. 2009). Recognising diverse wetland ecosystem services, and the multiple values that stakeholders hold for these services forms a cornerstone of effective management (Kumar et al. 2017).

The provision of ecosystem services relies upon the complexity and functioning of ecosystems and landscapes (Raudsepp-Hearne et al. 2010). Seen from the perspective of biophysical sciences, ecosystem services are an outcome of ecological production functions (Daily et al. 2009), which in turn are underpinned by biophysical structures and processes, often included within the category of supporting services (de Groot et al. 2010). The distinction of ecosystem functions from ecosystem components and processes has been highlighted, as the former encapsulates not just the combinations of the latter, but also the potential that ecosystems have to deliver ecosystem services (Naeem et al. 1999). The scales at which ecosystem services are produced, used and accessed provide a context for interpreting societal values that are attributed to these services and tools applied for their management (Raudsepp-Hearne and Peterson 2016).

Wetlands are multifunctional, delivering a range of ecosystem services, several of which respond to a similar set of drivers or ecosystem processes, and are therefore best treated as clustered bundles (Gonzalez-ollauri and Mickovski 2017; Raudsepp-Hearne et al. 2010), rather than stand-alone services. Tradeoffs between various ecosystem services bundles are inherent as not all services co-vary in response to wetland use and management (MEA 2005; Raudsepp-Hearne et al. 2010). Management that attempts to maximise the production of one ecosystem service (often a provisioning service) often results in substantial declines in the provision of other ecosystem services (often regulating and cultural services) (Bennett et al. 2009; Russi et al. 2013). Realigning management systems which reward the production of marketed provisioning services, but not the provision of non-marketed ecosystem services, such as regulating and cultural services, remains a fundamental concern (Guerry et al. 2015). An important appraisal element for wetland management which follows herefrom is whether the diversity of ecosystem services (and bundles) are considered while framing management objectives; and whether the underpinning ecosystem functions that sustain these services are adequately addressed within management actions.

Ecosystem services represent a political framing of nature-society relationships, often creating new markets, property and power relationships for public goods, with such changes having distinct distributional consequences (Kull et al. 2015). The transformation of natural capital into ecosystem services is influenced by a suite of institutions that mediate these transformations at all levels (Duraiappah et al. 2014). These institutions mediate and influence social processes governing access, such as entitlements (Leach et al. 1999; Sen 1984), power asymmetries (Robards et al. 2011), social differentiation (Leach et al. 1999) and relative poverty. Power relations, embedded within institutional and governance systems, shape the ability of ecosystems to provide ecosystem services (Felipe-Lucia et al. 2015; Ribot and Peluso 2009). From a social dimension, it is thus important to understand how human actions lead to the generation of ecosystem services, who in society benefit from these services, and how are the values for these ecosystem services articulated for integration in decision-making (Ernstson 2013).

The interlinkages of ecosystem services with the biophysical and social system is often framed in terms of a cascade, with ecosystem properties, functions, services, benefits and values as building blocks (Nassl and Löffler 2015; Potschin-young et al. 2018). Use of this framework requires an understanding of the complexity of ecosystem components and processes, ecosystem functions, but also the pathways and scales of service flow, the diverse benefits and values, and importance of using appropriate evaluation procedures (Boulton et al. 2016). Value attribution to benefits derived from ecosystem services is subjective, based on criteria such as individual, stakeholder group, time, and location, or from normative criteria related to aspects such as culture, time and location set by institutions (Spangenberg et al. 2014). We use the cascade framework to reflect on the biophysical, social and governance elements related to the integration of ecosystem services within management of Chilika.

4.3 Ecosystem Services Within Management of Chilika

The ecosystem services cascade, representing the conceptual linkages between the Chilika social-ecological system, institutions and governance and contribution to human well-being, is presented in Fig. 4.1 We build on the description of Chilika social-ecological system discussed in Kumar et al. (this volume), and elaborate the remaining elements of the cascade here.

4.3.1 Institutions and Governance Settings

The CDA serves as the nodal government agency for the management of Chilika. The Authority's general superintendence is vested in its Governing Body, chaired by the Chief Minister of the Government of Odisha, and having elected representatives of the region around Chilika, heads of various government departments, and major scientific institutions as members. The Authority conducts its activities in line with an approved management plan, and secures funds for implementation of activities from the national government and partly from major donor agencies. The Governing Body also serves as a platform for coordinating sectoral development projects and taking decisions on various policy and regulatory matters. Based on this institutional structure, the CDA has been able to complement ecological monitoring and habitat management programmes with programmes on fisheries, rural development and tourism.

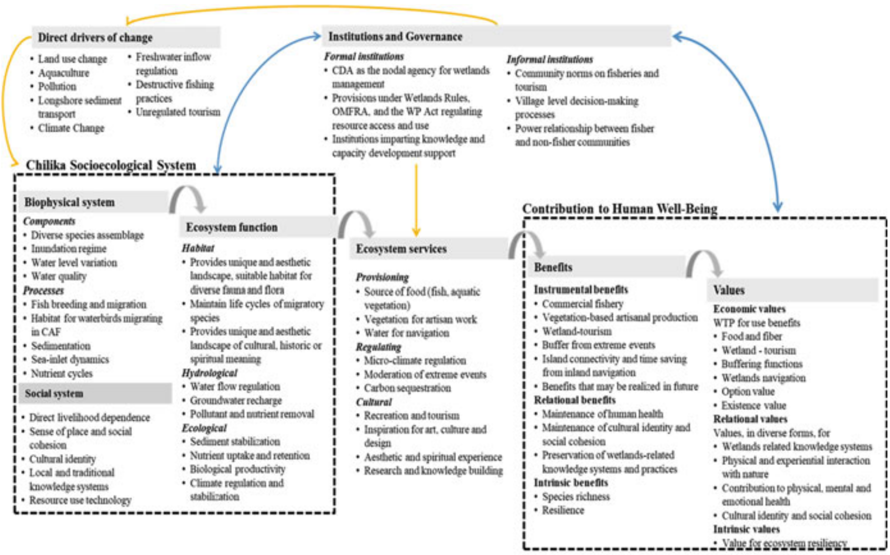

Fig. 4.1 The Chilika Ecosystem Services Cascade (based on Burkhard et al. 2010; Potschin-young et al. 2018)

Control, access and management of Chilika is based on several laws and regulation enacted by the national and the state governments. The Wetlands (Conservation and Management) Rules, 2017, notified under the Environment Protection Act (1986) sets several prohibitions, particularly on conversion of wetlands to non-wetland usages in Ramsar Sites, and requires management to be guided by an integrated wetland wise-use plan. In 2019, the Ministry of Environment, Forest and Climate Change (MoEFCC), Government of India issued the Coastal Regulation Zone notification, placing a range of development restrictions along the coastline. Seagrasses, biologically active mudflats and bird nesting grounds have been placed under the most stringent regulation under these rules. Management of Nalabana, a 15.5 km^2 island in the centre of Chilika, is guided by the provisions of the Wildlife Protection Act (1972) as the site was declared as a wildlife sanctuary in 1987. In 1984, the state government enacted the Orissa Marine Fisheries Regulation Act, under which fishing vessels, gears and fishing grounds are regulated by the State Department of Fisheries.

At the community level, village Panchayats are the formalised local self-government system entrusted with the responsibility of developmental planning and implementation in various spheres, including conservation of the local environment (Srivastava 2002). The formalisation of fishers access and use rights have evolved since the 1500s from a system of regulation by the king to vesting the rights in favour of the Odisha State post-independence (Nayak 2014). Since the 1960s, the Odisha State instituted a system of administering fishing area leases to the Primary Fishermen Cooperative Societies (PFCS). With the modernisation of fishing techniques, the introduction of aquaculture, and changes in lease policy in the nineties in favour of culture-based fisheries (Samal 2002), the lagoon witnessed an efflux of non-fishermen who gradually used their political and economic power to usurp the fishing grounds and convert shorelines into aquaculture areas (Dujovny 2009). While the shrimp culture was declared illegal in Chilika on the basis of an Odisha High Court Order of 1993 and Supreme Court order of 1996 (Nayak 2014), the power and economic asymmetries between the fisher and non-fisher communities have an important bearing on the benefit sharing from Chilika fisheries till date (Das 2018; Kumar et al. 2011).

Community institutions have historically been central to the management of Chilika fisheries. Based on a nuanced understanding of the resource, the fishers of Chilika evolved a system of resource partitioning by setting spatial limits (places to fish), temporal limits (seasonality), gear restrictions (what harvesting gear may be used), and physical limits (what sizes may be fished) (Sekhar 2004, 2007). Fishers also attach strong symbolic significance to the wetlands (revering it as mother nature), the dolphins (as a sign of good luck) and an abode of their goddess Kalijai, which has a temple on an island inside the wetland (D'Lima et al. 2014). With the resurgence of tourism since the opening of the new mouth in Chilika in 2000, fishers operating tourist boats have formed associations which allocate tourists to individual boats, and in the process reduce conflicts between boatowners.

4.3.2 Ecosystem Functions

Chilika provides diverse habitats suited for a range of species adapted to freshwater, brackish and marine environments. The lagoon is known to be inhabited by at least 259 phytoplankton (Srichandan et al. 2015), 77 zooplankton (CIFRI 2017), 44 macro-benthos (CIFRI 2017), 102 algae (Rath and Adhikary 2008), 726 plants, 126 molluscs (Mahapatro et al. 2016), 317 fish (Mohanty et al. 2015), 225 bird (Balachandran et al., this volume), 7 amphibian and 19 mammal species (Kumar and Pattnaik 2012), several of which are of high conservation significance globally and regionally. Chilika is also one of the two lagoons in the world inhabited by the Irrawaddy Dolphin (*Orcaella bervirostris*) (Reeves et al. 2008). *Barkudia insularis*, a limbless skink, is endemic to Chilika environs (Bauer et al. 2014). A population of about 30,000 water buffalo *Bubalus bubalis* has adapted to the saline condition of the lagoon and established as a separate breed (Singh et al. 2017) and even a source of geographical indication products such as Chilika curd (Nanda et al. 2013). Discovery of novel bacteria such as *Streptomyces chilikensis* (Ray et al. 2013) and *Halobacillus marinus* (Panda et al. 2018) indicate the bioprospecting potential of the lagoon.

Chilika also plays an important role in maintaining life-cycles of migratory species. For several waterbirds migrating along the Central Asian Flyway and East Asian Australasian Flyway, Chilika is an important stopover site (Balachandran et al. 2018; Palm et al. 2015). Of the 377 fish species documented in the lagoon thus far, 271 are migratory, and critically dependant on the wetland ecosystem to complete their lifecycle (Mohanty et al. 2015).

A sizeable waterholding capacity of nearly 1200 Mm^3 and an interannual tidal range of upto 0.6 m enables Chilika to absorb a significant proportion of monsoon flows. The mixing of freshwater from the Mahanadi River distributaries and seawater from the Bay of Bengal enables creation of a salinity gradient, with nearly freshwater conditions in the northern part, mixohaline conditions in the central and southern sector, and euhaline to hypersaline conditions in the outerchannel (Barik et al. 2017; Panda et al. 2015). The salinity gradient plays an important role in creating diverse habitats, regulating vegetation and providing migration cues to fishes (Kumar and Pattnaik 2012).

Chilika also serves as a sink for organic matter and nutrients, effectively recycling the inputs received through various transport processes resulting in regulation of nutrient and thus enhancing overall productivity (Amir et al. 2019; Ganguly et al. 2015). The dense *Phragmites karka* stands on the northern shoreline of the lagoon act as an ecological filter by trapping nutrients and pollutants and thus enabling maintenance of the water quality (Behera et al. 2018). Chilika harbours nearly one-fifth of the seagrass meadows of India (Geevarghese et al. 2018) which act as a carbon sink, sequestering annually 10.1–16.8 tCO_2 equivalent ha^{-1} in Chilika, and storing 22.4 tCO_2 equivalent ha^{-1} and 444 tCO_2 equivalent ha^{-1} in living biomass and soil organic carbon respectively (Ganguly et al. 2018).

The Chilika landscape has unique cultural, historical and spiritual significance. Archaeological investigations have indicated that the wetland was the site of important ports providing berthing facilities to ships travelling to Southeast Asian countries since 150 AD (Tripati and Patnaik 2008) and thus played an important role in the spread of Indian culture beyond India's shoreline (Tripati and Vora 2005). Chilika has also figured prominently in Oriya poetry (Mansinha 1960), and the works of noted Oriya poets such as Radhanath Ray and Gopabandhu Das. The lagoon has also been placed on the tentative list of sites under the World Heritage Convention (UNESCO 2014).

4.3.3 Ecosystem Services

Chilika, with 73 fish, prawn and crab species of commercial value (Mohapatra et al. 2007) is an important commercial fisheries for the state and the base of livelihoods of nearly 0.14 million fishers. The lagoon also contributes to off-shore fisheries, as many estuarine fish and prawn species use the wetland as spawning and breeding habitats. Several macrophytes are harvested for household and commercial use such as *Schoenplectus littoralis*, a cosmopolitan sedge (for making mats), *Phragmites karka* (for fuel and roofing material), and *Stuckenia pectinata* and *Naja sp* (for preserving fish catch). The extensive water expanse of Chilika allows for operation of inland navigation, providing connectivity to population living within the islands and leading to considerable time saving as compared with alternative road travel.

The immense water storage capacity within a densely populated area makes Chilika an important buffer for floods and cyclones which are known to frequently hit the east coast landscape. Evapotranspiration and heat storage enable large waterbodies as Chilika to regulate microclimates by taking away ambient heat and improving breeze circulation. Nutrient uptake and sediment retention within the lagoon prevents pollution within the coastal areas. Large swathes of sea-grasses and patches of mangroves enable storage and sequestration of carbon within biomass and sediments thus removing harmful greenhouse gases from the atmosphere.

With rich and biodiversity and scenic beauty, Chilika is a popular tourist destination on the Indian east coast, accounting for 8–10% of the total tourist arrivals in the state (Kumar and Pattnaik 2012). Balugaon, Satpada and Rambha receive the majority of tourists, who flock to watch waterbird congregations, Irawaddy Dolphins or just make a visit to the venerated Kalijai temple. The islands of the lagoon present a picturesque sight with the Khalikote hills as a backdrop. Chilika tourism forms the basis of a vibrant economy for the tourist boat owners, hoteliers and travel companies.

4.3.4 Benefits and Values

In line with the IPBES multiple values framework (Pascual et al. 2017), we classify benefits (and values) in three major categories, namely instrumental, relational and intrinsic. The instrumental benefits and values relate to Chilika being a source of food and fibre (through fisheries and aquatic plants), as a means of recreation which also provides livelihoods to a large population of dependent communities, and time-saving that result from the use of Chilika as a medium of inland transport. The category also includes benefits and values linked with the security of life and assets provided by buffering of floods and tropical cyclones, the avoided coastal pollution by filtering the runoff received from the direct catchments, and avoided impacts of climate change resulting from the carbon sequestered by the lagoon.

The relational benefits and values are related to the symbolic relationships that communities hold with Chilika, giving them a sense of identity and spirituality. Such values underlie the long-standing struggle of traditional fishers for fishing rights (Das 2018), the symbiotic relationship between the fishers and dolphins (D’Lima et al. 2014), and veneration of Chilika and Kalijai within various religious and cultural practices. The non-anthropocentric intrinsic benefit and value of Chilika are linked with the diversity of species and habitats within the lagoon, and the myriad ecosystem processes that connect the biotic and abiotic components of the ecosystem. Several elements of the intrinsic values have been explored through the ongoing monitoring programmes of the CDA and research carried out by different agencies, which also assist in managing wetlands placed in similar ecological and social contexts.

4.3.5 Drivers of Change

A range of natural and human induced direct drivers (directly influencing ecosystem processes) and indirect drivers (operating diffusely by altering one or more direct drivers) cause a change in ecosystem (Nelson et al. 2006). Direct physical and biological drivers of change operating in Chilika are changes in climate, coastal processes, land use in catchments, aquaculture and pollution loading. Climate change is manifesting in diverse ways including high rates of sea level rise in the Bay of Bengal as compared to other parts of the Indian coastline (Chowdhury and Behera 2015; Unnikrishnan et al. 2015), increasing frequency of cyclones (Unnikrishnan et al. 2011; Mishra 2014), lagoon surface warming (Schneider and Hook 2010), and high likelihood of flow reduction from Mahanadi River (Rao 1995; Mondal and Mujumdar 2015; Raje and Mujumdar 2010). The northwards littoral drift along the Bay of Bengal renders the coastal inlet prone to the impacts of shifting sand. During October 2000 to April 2018, the sea inlet at Sipakuda shifted northwards by 4.2 km. The mouth is also rendered dynamic, eroding and accreting at annual rates of 13.63 m and 13.9 m, respectively between 1988 and 2017 (Vivek et al. 2019).

Land use of Chilika catchment has a direct bearing on runoff and pollution received in the wetland. During 2011–2017, the built-up area in the basin increased from 6% to 17%, accounting for a decline in the area under forests (from 26% to 24.7%) and agriculture (36.3% to 29%) (CDA Unpublished Data).

The natural shorelines of Chilika, since the 1990s, have been encroached upon by shrimp aquaculture enclosures, despite being declared as illegal due to their adverse ecological and social impact (Galappaththi and Nayak 2017; Nayak and Berkes 2010). In 2018, 15,147 ha of shoreline were freed of illegal enclosures through an eviction action by the Chilika Development Authority (CDA, personal communication). Enhanced landscape aesthetics post-ecological restoration has led to a resurgence of tourism, particularly tourism linked with dolphin watching. However, there are indicators that this growth is fast reaching the carrying capacity of the wetland ecosystem, and if not well-managed, could turn into a driver of adverse change (Lima et al. 2018). Studies on petroleum hydrocarbon for the lagoon have exhibited higher concentrations in areas surrounding the jetties, attributed to the operation and maintenance of motorised boats, although the concentrations were found to be low and mostly benign to the aquatic environment (Mohanty et al. 2016).

4.3.6 Feedback Systems

The CDA maintains a network of hydrometric, tide gauging and water quality stations to assess the hydrological condition of Chilika on a real-time basis. The Wetlands Research and Training Center of the CDA researches ecological dimensions of the wetland, and publishes, on a bi-annual basis, an ecosystem health report card. The Annual General meetings of the authority are a means of sharing the information on the status of the lagoon to different development sectors. On an informal scale, the press and media regularly publish articles and clippings on issues related to Chilika. However, feedback mechanisms for social systems are relatively under-developed. Thus, information on the human well-being outcomes resulting from Chilika management is currently only peripherally included in the monitoring system.

4.4 Economic Values of Ecosystem Services Benefits

In this section, we present the economic values of select ecosystem services benefits of Chilika, namely commercial fisheries, aquatic vegetation for economic use, water transport, tourism and recreation, carbon sequestration and existence value.

4.4.1 Commercial Fisheries

CDA, since 2001, has been monitoring fish landings, marketing channels, prices at various trading locations and select biological paramters within the overall wetlands monitoring framework. An analysis of data for 2011–2015 indicates an average annual landing of 12,465 MT, of which fish, prawn and crabs constituted 57%, 40% and 3% of the quantity respectively. Prawns are the most valued component of Chilika fisheries. Of the total prawn landing, 43% is exported to international markets, with the trade almost restricted to three species, i.e. *Penaeus monodon, Fenneropenaeus indicus* and *Metapenaeus monoceros.* About a quarter (26%) is exported to other states, the rest traded around Chilika and adjoining districts. The fish landing is mostly traded as fresh fish (98.14%), and a minor proportion as live fish (1.03%) and dry fish (0.83%). Nearly half (47%) of total fish landing is exported to at least eight states, i.e. West Bengal, Jharkhand, Delhi, Madhya Pradesh, Tamil Nadu, Gujarat, Kerala and Andhra Pradesh. Local consumption, which occurs through markets around Chilika and consumption by the fishers forms the next major category (40%). 14% of the total fish catch is also traded within the western and southern districts of Odisha State. Of the total crab landing, 52% is reported to be exported to other states, with the rest being traded in markets within the state.

The gross economic value of Chilika fish, based on price and quantity data across various market segments and trading agents is presented in Table 4.1. Prices used for each market segment have been quantity weighted.

Table 4.1 Estimation of gross economic value of Chilika fisheries

	Fish	Prawn	Crab	Total
Amount traded (in MT)				
(a) within Chilika	2610.36	995.07	–	3605.43
(b) within Odisha state	859.40	326.27	185.18	1370.85
(c) Exported outside Odisha state	3677.76	1341.75	154.02	5173.53
(d) Exported to international markets	–	2315.75	–	2315.75
	7147.52	4978.84	339.21	12,465.57
Quantity sold to (in MT)				
(a) Retailers	765.08	536.08		1301.16
(b) PFCS	5079.73	3529.99		8609.72
(c) Intermediaries/commission agents	1302.70	912.78	339.21	2554.69
Quantity weighted prices (Rs. per kg)				
(a) Retailers	94.12	214.28	165.60	
(b) PFCS	78.43	178.57		
(c) Commission agents	62.13	131.58	138.00	
Gross value (in Rs. Million)	551.35	865.33	46.81	1463.48

4.4.2 Aquatic Vegetation for Economic Use

A household survey of 4074 households conducted during September to November 2012 indicated that 8400 MT of *Phragmites karka* was harvested annually for use as fuel and as thatch, 3836 MT of *Schoenplectus littoralis,* and 1900 MT of *Potamogeton pectinatus and Naja sp.* for use as packing material by fishers. Valuation of use of *Schoenplectus littoralis* for mat-making is based on the price of the final product. Valuation of use of *Phragmites* has been derived using the opportunity cost of time-based on the prevailing rural wage rate. Similarly, the opportunity cost of time spent in transporting the harvest of packing material to shoreline is used as a proxy price. Using these prices, the economic benefit from use of aquatic plants has been assessed to be Rs. 34.31 million.

4.4.3 Water Transport

Water transport in Chilika caters primarily to two segments, the first being the island villages having limited road connectivity, and the second being the tourists. Benefit to the tourists have been included within the consumer surplus estimates for tourism in the latter section. The CDA operates a passenger ferry between the islands on a no profit-no loss basis. During 2003–2014, water transport in Chilika was annually availed by 35,600 persons, with an average time cost saving of 4.5 h per person when compared with an alternate road route. Assuming that the proportion of working population within the passengers is similar to that of the regional average (42%), the opportunity cost of time saved based on the average rural wage rate is assessed to be Rs. 13.6 million.

4.4.4 Tourism and Recreation

Individual Travel Cost Method (ITCM) has been used to estimate tourism and recreational benefits from Chilika. Demand curves relating the annual site visitation rate (every 10 years) to the per capita visit costs, income, and other socioeconomic characteristics have been estimated separately for the domestic and foreign tourists. A questionnaire survey of tourists to elicit the overall economic value attributed to wetland based tourism was carried in and around Chilika during September – November 2012. Overall, 433 tourists responded to the survey, of which 36 respondents were of foreigners and the rest Indian nationals. Of the total responses received, the survey forms of 179 of the domestic tourists and 31 the international tourists were complete in all respects and used for estimating consumer surplus. Individual consumer surplus was aggregated to the total site arrival for estimation of the overall consumer surplus for the site. Following model was estimated:

$$\overline{CS} = \left(e^{c} * \overline{trip\_dur}^{\beta_1} * \overline{dist}^{\beta 2} * \overline{jour\_pur}^{\beta 3} * \overline{gsize}^{\beta 4} * \overline{income}^{\beta 5} * \overline{age}^{\beta 6} \int_{tc\,\min}^{tc\,\max} tc^{\beta 7} d(tc) \right.$$

$$= \left(e^{c} * \overline{trip\_dur}^{\beta_1} * \overline{dist}^{\beta 2} * \overline{jour\_pur}^{\beta 3} * \overline{gsize}^{\beta 4} * \overline{income}^{\beta 5} * \overline{age}^{\beta 6} * \left[\frac{(tc)^{\beta 7+1}}{\beta 7 + 1} \right]_{tc\,\min}^{tc\,\max} \right.$$

(trip_dur: Trip duration in days; dist: Distance travelled to Chilika (km); jour_pur: dummy variable indicating purpose of journey; gsize: Number of persons accompanying group; income: Annual income of the household (in Rs. for domestic tourists and US$ for international); age: age of the respondent (years); tc: average trip cost per person (in Rs. for domestic tourists and US$ for international)) (Table 4.2)

The predictors explain 54% and 45.5% of the variability in the visitation rate for domestic and international tourists, respectively. For domestic tourists, the visitation rate was found to be negatively related to distance, group size and per person trip cost. For international tourists, trip cost per person was the only variable which was found to be significantly and negatively related to visitation rate. The annual average consumer surplus based on the demand curve was estimated to be Rs. 5806.82 for domestic tourists and US$ 2686.56 (equivalent to Rs. 170,597 at 2015 exchange rate). The aggregate consumer surplus, estimated based on average annual arrivals during 2010–2014, has been estimated to be Rs. 3027.34 million for domestic tourists and Rs. 351.77 million for international tourists. The two categories sum to Rs. 3379.11 million annually.

Table 4.2 Regression model for estimation of travel cost

Parameter		Coefficients modelled for Domestic Tourists	Coefficients modelled for International Tourists
Adjusted R^2		.540	.455
DW statistic		1.948	2.240
N		179	31
F statistic		28.674**	32.05*
Ln (trip_dur)	Natural logarithm of duration of trip (days)	−.108	−0.004
Ln (dist)	Natural logarithm of distance travelled to Chilika (km)	−.420**	@
Ln (jour_pur)	Natural logarithm of dummy variable indicating purpose of journey	.147	−0.008
Ln(gsize)	Natural logarithm of number of persons accompanying group	−.173**	−0.0064
Ln (income)	Natural logarithm of annual income of the household (in Rs. for domestic tourists and US$ for international)	0.016	−0.126
Ln (age)	Natural logarithm of age of the respondent (years)	.102	0.273
Ln (tc)	Natural logarithm of average trip cost per person (in Rs. for domestic tourists and US$ for international)	−.181**	−0.225*
Constant		4.303**	0.718

**significant at 99% confidence interval, *significant at 95% confidence interval, @not used as predictor in regression model

4.4.5 Carbon Sequestration

The economic value of blue carbon sequestered by seagrass in Chilika has been estimated using the following equation:

$$VC = SQ * A * SCC$$

Wherein VC: Economic value of carbon sequestered, SQ: Rate of carbon sequestration (in t CO2 equivalent ha^{-1} $year^{-1}$); A: Area under seagrass (in ha); SCC: Social cost of carbon (Rs per t CO2).

Ricke et al. (2018) based on climate model projections, climate-driven economic damage estimation and socio-economic projections have estimated India's Social Cost of Carbon to be between US$ 49–157 per t CO2, with an average of US$ 86, equivalent to Rs 5693 at 2015 exchange rate. With a seagrass extent of 8660 ha and a rate of carbon sequestration ranging between 10.1–16.8 t CO2 equivalent ha^{-1} $year^{-1}$ (Ganguly et al. 2018), the economic value of blue carbon in Chilika has been estimated to range between Rs. 498–828 million $year^{-1}$.

4.4.6 Existence Value

Closed-ended Willingness to Pay (WTP) data was obtained from a survey of 984 residents around Chilika carried out during September – November 2012. The WTP was assessed using a logit model to identify the determinants of the responses to the question: "Yes, I am willing to pay Rs. X for conservation and wise-use of Chilika" or "No, I am not willing to pay Rs. X for conservation and wise use of Chilika", where X refers to the amount of closed bid in each case. The model relates the 1 (yes) and 0 (no) response variable to the bid levels faced by each respondent.

The general form of the model is expressed by the following equation (Cox 1958):

$$P_i = E(Y = 1|X_i) = \frac{1}{1 + e^{-(\beta_1 + \beta_2 X_i)}}$$

Wherein, P_i is the probability of an individual i willing to pay the stated bid amount X_i. Using a logit regression to relate individual responses to the bid values results in estimates of coefficients β_1 and β_2, which can be used to derive the mean WTP. The coefficients were estimated to be −0.005 and 3.829 respectively, both significant at 99% confidence interval. The coefficient β_2 is negative and significant, indicating that the probability of accepting a particular bid level decreased with an increase in the bid amount. The Hosmer and Lemeshow Test yielded a significance value of 0.005. The Cox and Snell R Square and Nagelkerke R Square values were estimated to be 0.382 and 0.509. The model estimated "no" and "yes" values 89.1% and 70.9% correctly, with an overall percentage correctness of 80.1%. The estimated mean WTP per respondent is Rs. 257.63. The aggregate existence value, by extrapolating the mean WTP to the total number of households living in and around Chilika has been estimated to be Rs. 17.32 million.

4.5 The Economic Efficiency of Investment in Wetland Restoration

The costs related to managing Chilika are currently met through the financing of specific projects by the Central and State Governments. The primary source of Central Government assistance is from the MoEFCC under its national scheme on wetlands, titled National Plan for Conservation of Aquatic Ecosystems. Funding to wetlands of national priority is at times also included as a Grant-in-Aid for special problems as per the recommendation of the Finance Commission of the Government of India, routed through the Ministry of Finance.

Based on the data provided in annual reports and account statements, the CDA during 1992–2014, entailed an expenditure of Rs. 1545.55 million (equivalent to US $ 22.78 million at 2016 exchange rate) for various restoration interventions. A major proportion of funding (76%) was received in the form of Grant-in-aid by the Finance Commission of Government of India (tenth, eleventh, twelfth and thirteenth). The balance of the funding was received from the MoEFCC and the State Government of Odisha (5% and 7% respectively). Nearly half (46%) of the expenditure has been on the maintenance of hydrological regimes (maintaining connectivity with the Bay of Bengal). Approximately, one fifth of the investment (19%) has been made on wetland monitoring and evaluation and another one fifth on fisheries development and livelihood improvement.

A benefit-cost ratio has been computed as an indicator of economic efficiency (Pearce 1998) of the investment made in the management of Chilika. Expenditure by CDA on different management components have been treated as public investments. Private investments for fisheries and tourism have been considered, as these form an integral component of total capital deloyed for accessing ecosystem services benefits. Data on capital costs incurred by the fishers were derived from a survey of fishers conducted in 2012, and the values extrapolated for the past years assuming an inflation rate of 6%. For tourism, it is assumed that 90% of the tourist expenditure spent locally for travel accommodation and food are invested (estimated from tourist expenditure data collected during ITCM survey). The per capita tourist expenditure estimated separately for domestic and international tourists for 2012 have been extrapolated for the previous years using an inflation rate of 6%, assuming that the proportion of local expenditure does not change over time.

Incremental benefits from fisheries and tourism were included in the benefit stream. In the case of fisheries, incremental landing for the period 2001–2014, over an average landing of period 1991–2000 has been used for analysis. In the case of tourism, incremental tourist arrivals since 2001, over average arrival for the period 1994–2000 have been assessed. The consumer surplus for domestic tourists estimated in 2014 was adjusted for various years using data on the consumer price index. Surplus for international tourists of 2014 was adjusted using a ratio of US$-Rupee exchange rate for a given year to that of 2014. The benefit-cost ratio on the basis of public investment is 16.2. When the private investment in also included, the ratio is 3.73 (Table 4.3).

4.6 Distributional Aspects of Benefits from Chilika Fisheries

One of the objectives pursued by Chilika management is to rejuvenate the PFCS to ensure better economic returns to the capture fishers as an incentive for responsible fishing. Since 2008, the CDA has been implementing a Fisheries Resource Management Plan (FRMP) (JICA and CDA 2009) which focuses on enhancing the capacity of the fishery cooperatives through measures as capital infusion, training in accounting, provision of ice boxes, creation of landing centres, and creating awareness on responsible fisheries.

Table 4.3 Composition of costs and benefits from Chilika restoration (Rs. Million)

Total Costs			9405.09
Public investment		2161.76	
Habitat management	320.08		
Wetland monitoring and research	73.59		
Wetland monitoring and evaluation	394.67		
Socioeconomic improvement and livelihoods	246.50		
Livelihoods	203.54		
Improvement of water exchange	923.38		
Private investment		7243.33	
Depreciated value of boats and machinery	1362.51		
Depreciated value of tourism infrastructure	5880.82		
Total benefit		35,039.74	35,039.74
Value of increased fish landing	14,261.39		
Value of increased tourism	20,778.34		

A comparative analysis of the distribution of economic benefits from Chilika fisheries has been conducted for the period of 2008 (prior to efforts placed for rejuvenation of PFCS) and 2015 (wherein major components of Fisheries Resource Management Plan had been implemented). The 2008 scenario has been constructed using data on fish landing, landing center prices and catch disposal accessed from the CDA. These data were complemented by sample survey of 4133 households on occupation pattern, asset ownership, pattern of catch disposition, point of sale, prices obtained, workforce participation, indebtedness, and ownership of fishing equipment. The situation of 2015 was assessed based on a survey of 8 PFCS (3877 fishers).

The gross revenue earned from fishing has been derived using data on quantity weighted prices at various points of sale (namely PFCS, commission agent, mahajan, retailer or direct to consumer) with quantities sold at various points. The net revenue has been estimated by reducing the capital expenses (depreciation of boats, nets and gear, costs of fuel for fishing fleet) from the gross revenue. To ensure comparability, the 2008 prices were adjusted to 2015 using the Consumer Price Index (Rural) data. In the case of catch handled by PFCS, the operational costs paid to the society (Rs. 5 per kilogram of fish and Rs. 7 per kilogram of prawn) have been deducted from gross revenue, in addition to costs of capital deployed. The gross revenue realized to the fisher has also been expressed in terms of percentage of the total value estimated from the highest landing centre price for the catch. This proportion is a proxy indicator of the share of fishers in the value of fish landed if sold at the local market. The gross and net revenues have been expressed in terms of per household income using the 2010 assessment of the number of fisher households (23,115) (Kumar and Pattnaik 2012). The daily wage rate earned for fishing activity has been derived by dividing net revenue by the number of fishing days.

Data from the surveys indicate a distinct change in prices and points of sale during the period 2008–2015. Since the FRMP was implemented, the PFCS offered

Table 4.4 Changes in gross and net revenue to fishers (2008 and 2015)

Particulars	Survey year	
	2008	2015
Total fish, prawn and crab landing (in '000 kg)	10,051.36	12,053.56
Gross value of the fish catch realized to fishers (in Rs. Million)		
(a) At current prices	645.00	1332.48*
(b) At 2015 adjusted prices	810.71	
Gross value at highest landing center price (in Rs. Million)	1009.51	1917.03
Value realized to fishers as a proportion of value estimated using maximum local prices	53.91%	69.51%
Gross annual income per fisher household (Rs.)		
(a) At current prices	23,502.33	57,645.72
(b) At 2015 adjusted prices	35,072.71	57,645.72
Net annual income per fisher household (Rs.)		
(a) At current prices	16,684.70	43,046.62
(b) At 2015 adjusted prices	24,898.71	
Daily wage rate earned per fishing day (Rs.)	109.84	195.69

*The gross value reflected here differs from the one reflected in Table 4.1 which is computed on the average catch for the period 2011–2015

higher prices to the fisher as compared with the middlemen. For prawns, the quantity weighted price offered by the cooperative to its member fishers was estimated to be Rs. 178.57, which was 35% higher than that paid by the middlemen. Similarly, the quantity weighted price of Rs. 78.43 per kilogramme of fish offered by the cooperative to its members was 26% higher than that paid by the middlemen. The surveyed fish cooperatives did not report trading in crabs. However, there is still a sizeable proportion of catch sold to commission agents, as the cooperatives handled only 71% of the fish and prawn landing by its members.

Apart from changes in prices and trading points, the differences in per household gross and net income and the wage rate is also due to the fact the catch in 2015 was 19.9% higher. If the fish landing in 2008 were to be considered equal to that of 2015, the difference in gross annual household income (at prices adjusted to 2015 for comparability) within the two periods is of 24.5% (Rs. 57,645 in 2015 as compared with Rs. 46,298 in 2008). Similarly, the estimated wage rate in 2015 is 19.2% higher (Rs. 189.89 in 2015 as compared with Rs. 159.36 in 2008) (Table 4.4).

4.7 The Value of Ecosystem Components and Processes

A production function approach (Barbier 2007; Mäler 1991) has been used to analyse the contribution of ecosystem components and processes towards generating ecosystem services benefits from commercial fisheries. The production function has been specified as $q = q(m, n)$, wherein, q is the output (fish landing), m denotes the vector of manufactured and the human capital input and n denotes the vector of ecosystem components and processes as inputs.

The vector of ecosystem components and processes included in the model are in the form of two proxies, namely salinity and distance of sea inlet from the central sector. Within Chilika, salinity is an integrative indicator of ecosystem health, and provides cues for fish migration (Kumar and Pattnaik 2012). It also indicates the extent to which freshwater received from the Mahanadi Delta Rivers and seawater from the Bay of Bengal can mix (Panda et al. 2015). The distance of the mouth from the central sector of Chilika impacts key ecosystem processes such as tidal prism, tidal flux, and exchange of species between sea and lagoon. The vector of human and manufactured capital input into fisheries is described by the number of active fishers, number of boats and extent of fleet mechanization (the ratio of number of unmechanized boats to the number of mechanized boats). The first two variables are indicators of increase in human effort, while the latter has been used as a proxy for technology. The production function is estimated by the following stages:

$$mech_p = f(value\_curr, exd, prawn\_r, policy) \tag{4.1}$$

$$landing = f\left(mech_p, salinity, dist, fisher, boat\right) \tag{4.2}$$

It is assumed that (2) can be specified as a Cobb-Douglas function in the following form:

$$landing = \propto \left(mech_p\right)^{\beta 1}(fisher)^{\beta 2}(boat)^{\beta 3}(salinity)^{\beta 4}(dist)^{\beta 5} \tag{4.3}$$

With the coefficients, ß1, ß2, ß3, ß4 and ß5 representing output elasticity, and their sum determines returns to scale.

In Eq. (4.1), the extent of fleet mechanization has been estimated from the per fisher catch value at current prices (value_curr), exchange rate differential from the previous year (exd), the ratio of prawn landing to total landing (prawns) and the a dummy fisheries policy variable (policy). The per fisher catch value is a proxy for income generation, which in turn determines the ability to invest. The exchange rate differential is an indicator of export profitability, as a significant component of Chilika high-value prawns is exported to markets in Europe and Japan. The ratio of prawn to total landing is a proxy for landing composition, especially towards higher economic value species. The policy dummy variable captures the transition from a community-driven fisheries to prioritization for aquaculture and reversal thereof since the Supreme Court ordered a ban on aquaculture, and implementation of FRMP by CDA (Nayak 2017).

The function has been developed using annual time series data for the period 1957–2010. Data on landing, proxy for wetland's finfish and shellfish productivity is based on the data contained in Biswas (1995), CDA (2005) and monitoring records of CDA. The current value of landing has been derived using a quantity-weighted

Table 4.5 Regression estimates

Variable	Description	N	Mean ± SD	Coefficient
Equation 1: R^2 = 0.897, DW Statistic = 1.398, F Statistic = 104.561**				
$mech_p$[a]	Ratio of non-mechanized boats to mechanized boats	53	0.80 ± 0.17	
value _ curr	Current value of fish catch per fisher	53	0.80 ± 0.17	−1.195E-5**
exd	Difference between US$ to INR exchange rate in the current year with that of previous year	53	7534 ± 9836	−0.014*
prawn _ r	Ratio of prawn landing to total fin and shellfish landing	53	0.23 ± 0.07	0.804**
policy	Dummy variable (1 = policy favouring community fisheries, 2 = policy favouring aquaculture, 3 = policy favouring integrated management)	53	1.45 ± 0.66	−0.129**
Constant				0.896**
Equation 2: Adjusted R^2 = 0.404, DW Statistic = 2.219 , F Statistic = 4.746**				
Ln (landing) [a]	Natural logarithm of Total finsfish and shell fish landing (MT)	43	10.02 ± 0.34	
Ln (salinity)	Natural logarithm of Average lake salinity (in parts per thousand)	43	2.20 ± 0.36	0.264
Ln (fisher)	Natural logarithm of Number of active fishers (individuals)	43	10.02 ± 0.35	−0.774
Ln (boat)	Natural logarithm of Number of boats (number)	43	8.23 ± 0.27	0.217
Ln ($mech_p$)	Natural logarithm of Ratio of non-mechanized to mechanized boats (projected from equation 1)	43	−0.29 ± 0.22	−1.050*
Ln (dist)	Natural logarithm of Distance of the wetland mouth to the sea from central sector (in km)	43	2.88 ± 0.47	−0.861**
Constant				16.180

[a]Dependant variable, **significant at 99%,*significant at 95%

price data series, constructed from the information contained in (Biswas 1995; CDA 2005; Jones and Sujansingani 1954), and surveys conducted by authors in 2014. Trend data on the number of fishers, total boats and mechanised boats is based on linear interpolation for 1957 (Mitra and Mahapatra 1957), 1986–1987 (Satyanarayana 1999), 1996–2004 (CIFRI 2007; Mohapatra et al. 2007) and for 2007 based on surveys by authors. The series on salinity is based on data contained in (Biswas 1995), (CIFRI 2007) and CDA wetland monitoring database. Series on the exchange rate has been developed using the database from Reserve Bank of India at www.rbi.org. A linear specification of Eq. 4.1 gave the best fit, whereas Eq. 4.2 was modelled using log-linear specification. Details of regression estimates are presented in Table 4.5.

Both the regression models are statistically significant. Being time series, the regression did suffer from autocorrelation effects. For Eq. 4.1, the Durbin-Watson

Table 4.6 Estimation of the contribution of ecosystem variables to fisheries

	Pre-restoration period (1991–2000)	Post restoration period (2001–2010)	Change
Salinity (in ppt)	6.80	11.57	3.68
Distance (in km)	23.32	7.89	(16.52)
Modelled landing (MT) (controlling for all other variables)	3986.45	11,920.05	7933.59

(DW) statistics fell in an indeterminate zone, whereas the residual plot indicated randomness. The initial log-linear solution for Eq. 4.2, however indicated significant positive autocorrelation (DW = 0.705), thereby requiring application of Cochrane-Orcutt estimation procedure. The resultant model is able to explain 40.4% of the variability within the independent variable. The signs of coefficients are as expected. Since the mechanization ratio is coded inversely (a higher value indicating non-mechanization), it is indicated to be negatively related to current value of fish catch per fisher and policy changes in favour of community management. Within Eq. 4.2, landing is indicated to be negatively related to distance and mechanization. This is in line with the known fact that a decrease in mechanization ratio (and thereby an increase in number of mechanized boats) increased fish landings. Similarly, an increase in the length of channel has been observed to reduce landings significantly, due to its known impacts on migration and lagoon-sea connectivity. While an increase in boats is indicated to be positively related with landing, an increase in fisher is negatively related. This might be due to excess number of fishers not contributing to a commensurate increase in landing, or even reduced incremental landing.

To arrive at the incremental contribution of change in vector of ecosystem functions, the values in a pre-restoration period (pertaining to the period 1991–2000) have been contrasted with a post restoration period (2001–2010), while controlling for the variables representing human and manufactured capital. As can be seen below, the change in ecological parameters leads to an incremental landing of 7933.59 MT. This forms 72% of the average landing for the 2001–2010 period, and if valued at 2014 quantity weighted prices, comes to Rs. 1149.06 million (Table 4.6).

4.8 Managing Chilika for Multiple Ecosystem Services

4.8.1 The Relevance of Multiple Ecosystem Services for the Management of Chilika

The perspective of conserving multiple ecosystem services is complementary to the traditional framing of conservation strategies around biodiversity, habitat complexity and ecosystem processes (Ormerod 2014). The approach entails a progression from a siloed approach to conservation of species and habitats to explicit consideration of benefits humans derive from these ecosystems, enabling anticipation of a wide range of consequences that may result from different management regimes, and provide tools for identifying, negotiating, avoiding, and managing potential negative tradeoffs (Ingram et al. 2012).

Management of Chilika has historically been centered around fisheries, and since the site's designation as a Wetland of International Importance, for biodiversity values of global significance. The integrated management plan, formulated post hydrological restoration, seeks to achieve wise use of Chilika by meeting twin objectives of ecological security as well as livelihood improvement of local communities. The ecosystem services framework widens the scope of wetland management to not just include the instrumental relationships (such as providing food and nutritional security, security to assets, income generation and recreation opportunities) but also relational linkages (such as role of wetlands related knowledge systems; physical and experiential interactions with nature; contributions to physical, mental and emotional health; and cultural identity and social cohesion). Similarly, in terms of spatial scales, the framework enables the setting of management objectives not just in consideration with the local environment, but also to the wider basin and coastal zone (primarily through regulatory services), and even global scale (such as a role in carbon sequestration). At the same time, management strategies need to be based on a consideration of spatiotemporal variance of these ecosystem services bundles, because this variance underpins the resilience of the ecosystem that, if weakened, may affect its capacity to deliver ecosystem services (Boulton et al. 2016).

Hydrological processes and functioning are key drivers of the many physical and biochemical interactions within ecosystems, which in turn control the performance of the services beneficial to humans. From a management perspective, the snapshot information presented by economic values need to be interpreted alongwith information on status and trends of underpinning ecosystem functions as well as drivers of change. An assessment concluded in 2016 indicated that catches of three commercially important fish species (*Mugil cephalus*, *Daysciaena albida*, and *Eleutheronema tetradactylum*) were seriously declining, and a major proportion (65–88%) of specimens of five commercially important species were immature, indicating overfishing (CIFRI 2017). The analysis also raises serious concerns on fishing along the two migratory pathways leading to wanton destruction of post larvae and juveniles of commercially important fish and shrimp species (CIFRI 2017). The overall catch also hovers close to the maximum sustainable yield (CIFRI 2007).

There are tradeoffs inherent in managing Chilika. It is apparent that management aimed at enhancing provisioning services (such as fisheries) or cultural services (such as tourism) may be at the cost of regulating services (such as ability to buffer hydrological regimes, recycle nutrients and sequester carbon) or even ecosystem functions (such as habitat diversity). At catchment scale, intensification of land and water use may alter the state of wetland towards higher salinity or nutrient enrichment, with a cascading effect on several ecosystem services. The primary approach of the CDA to manage such tradeoffs is to maintain the state of wetlands as achieved after the opening of the new mouth to the sea in September 2000. There is an emphasis on permitting only capture fisheries in the lagoon. Aquaculture, which involves physical transformation of the shoreline is not permitted as a part of the management strategy. However, there are no mechanisms in place to regulate impacts of anthropogenic activities such as fisheries and tourism on ecological sensitive areas of the lagoon, such as the portion inhabited by sea-grass beds, fish migratory channels or used as habitat of Irrwadday Dolphins.

4.8.2 Addressing the Issue of Distributional Equity of Ecosystem Services

Chilika management has a developmental objective of enhancing economic returns to the primary fishers as an incentive for responsible fishing (Kumar and Pattnaik 2012). The analysis of distributional aspects of benefits from Chilika fisheries presented in the paper indicate the dampening impact of the existing market structure on the economic returns to primary fishers. Measures taken for strengthening the PFCS have led to a 26–35% increase in prices at which the member fishers are able to trade their landings. At comparable landing and current prices, during 2008–2015, the gross annual household incomes have increased by 25%, and the estimated wage rate per fishing day by 19%. The daily wage rate earned per fishing day wage rates that have been derived from the assessments are comparable with the minimum wage rates for unskilled labour in rural sector, yet are considerably lower than the minimum wages rates for semi-skilled and skilled categories. The overall value realization to the fishers remains low, as despite forming 93% of the workforce, their share in value generation remains only 70%. Beyond economic benefits, strengthening community institutions also has distinct social and institutional impacts, in the form of increased cohesion, reduced conflicts, representation capability and ultimately increasing the possibility of implementing responsible fisheries (Agrawal and Benson 2011; Allison et al. 2012; Jentoft 2000). However, purely from an economic perspective, the scope of management would need to include measures for reducing fishing effort, increasing value realization through strategies as product differentiation, and enhancing participation of fishers in the higher segments of value chain.

4.8.3 Capturing Economic Values of Ecosystem Services

The assessment of economic values presented in the paper indicate the value of Chilika as a natural capital, and the fact that investment in wetland restoration makes a strong economic sense. This calls for putting in place financial mechanism to ensure that management is sustained over time, and enough budgets made available for implementing various management actions. Core functions such as wetlands monitoring cannot be delivered through projects based financing alone, as these are prone to funding gaps.

Through the case of Chilika fisheries, the economic analysis underlines the significant contribution of ecosystem components and processes in the delivery of ecosystem services, and thereby the need to consider the joint production character in management decisions. The current economic model factors in the costs of human capital (such as fleet, crafts and gears) in private pricing decisions, whereas the costs of maintaining the ecosystem components and processes have been shifted to the public budget. Such a financing system is untenable in the long run, as the public funding for financing wetland restoration has several competing interests. It is thereby pertinent that the financial flows emanating from the ecosystem services of the wetland are linked with the costs of maintaining such services. Within commercial fisheries, it is important that the prices also signal the resource base quality, and thereby are able to attract a premium, part of which could be reinvested into the wetland management. Within tourism, a levy charged on tourists vehicles and hotels can generate resources for ensuring that core functions of wetlands management are sustained.

4.8.4 Governance for Multiple Ecosystem Services

The mapping presented in Sect. 4.3 of the paper indicates a maze of formal and informal institutions which influence the management of the Chilika social-ecological system. The institutional fit (Folke et al. 2007) of this arrangement with the social-ecological system properties of Chilika is a critical ingredient of successful management. Over a period of time institutional arrangements for management of provisioning services and select cultural services (mainly tourism) have emerged, however, there is a relative vacuum when it comes to management of regulating services (such as water regime moderation, nutrient cycling, carbon sequestration and others). While CDA has been mandated to ensure Chilika is managed for multiple ecosystem services, the organization's ability to influence underpinning ecosystem processes, particularly those nested within the basin and coastal zone scale land and water use is limited.

Even within provisioning services such as fisheries, not all management actions are complementary and mutually reinforcing. Not all elements of community-scale fisheries resources management by PFCSs are supported by a production driven approach of the state fisheries department. The Governing Body of Chilika performs an important role as a bridging organization by enabling links between a diverse set of actors across management levels and institutions boundaries, however the mechanism has become top-heavy over a period of time, with reduced participation of primary user groups (Nayak and Berkes 2011).

There is also a mismatch between the geographic scale of Chilika ecosystem functioning (operating at the scale of basin and coastal zone) and institutional arrangements for managing the wetland (which is directed mostly towards and within the boundary of the wetland). Much is dependent on the extent to which the institutions responsible for managing various sectoral development programmes (such as rural development, water and sanitation, disaster risk reduction) take into account the multiple ecosystem services of Chilika and the implication of development programmes for sustained provision of such services. The capability of CDA to be able to accommodate private or communal ownership of common pool resources (relevant for provisioning services), while at the same time providing conditions whereby public goods (relevant for regulating and cultural services) will not decline in unsustainable rates, is central to this arrangement (Fig. 4.2).

4.8.5 Monitoring Ecosystem Services

Over the years, the CDA has developed a sophisticated wetlands monitoring system which is able to track status and trends in various wetland ecosystem components (such as species and species assemblages, water and sediment quantity and quality), processes (such as sedimentation, species migration, and interaction with Bay of Bengal) and through sporadic research, interlinkages between the two (such as impact of emergent macrophytes on hydrological processes). Novel attempts to synthesize the monitoring information into communicable ecosystem health metrics have also been made recently, in the form of ecosystem health report cards, published biannually (CDA 2017). However, the current monitoring system tracks only a few ecosystem services indicators, mainly those related to fisheries, tourism and habitat services. Sampling protocols designed to monitor biodiversity and physical environment may not always be suited to generate indicators of ecosystem services (Geijzendorffer and Roche 2013).

Much can be gained by aligning current ecologically oriented monitoring towards a trans-disciplinary system which effectively bridges the divide between research and management (Steffen 2009). For measuring and managing ecosystem services, a social-ecological systems research and monitoring framework which can account for how these services are generated by coupled social-ecological systems (how different ecosystem services interact, how changes in the bundles of ecosystem services influence human well-being (Reyers et al. 2013), and how values for ecosystem services feed into stakeholder behavior and attitudes towards wetlands conservation and wise-use. Aspects such as the impact of changes in land use, nutrient mobilization, connectivity with the sea and rivers, species composition, and climate change on ecosystem services of the lagoon need to be systemically investigate for informing wetland management. An ecological research agenda for ecosystem services may be structured around four key areas: (a) identifying species, assemblages, or ecosystem processes that are key ecosystem services providers, and characterizing their functional relationships; (b) determining aspects of community structure that influence ecosystem functions within the Chilika basin and coastal zone; (c) assessing key environmental factors that influence the provision of services; and (d) measuring the spatio-temporal scale over which providers of ecosystem services operate (Kremen 2005). An empirical base for understanding thresholds of massive persistent changes in social–ecological systems, the factors that control

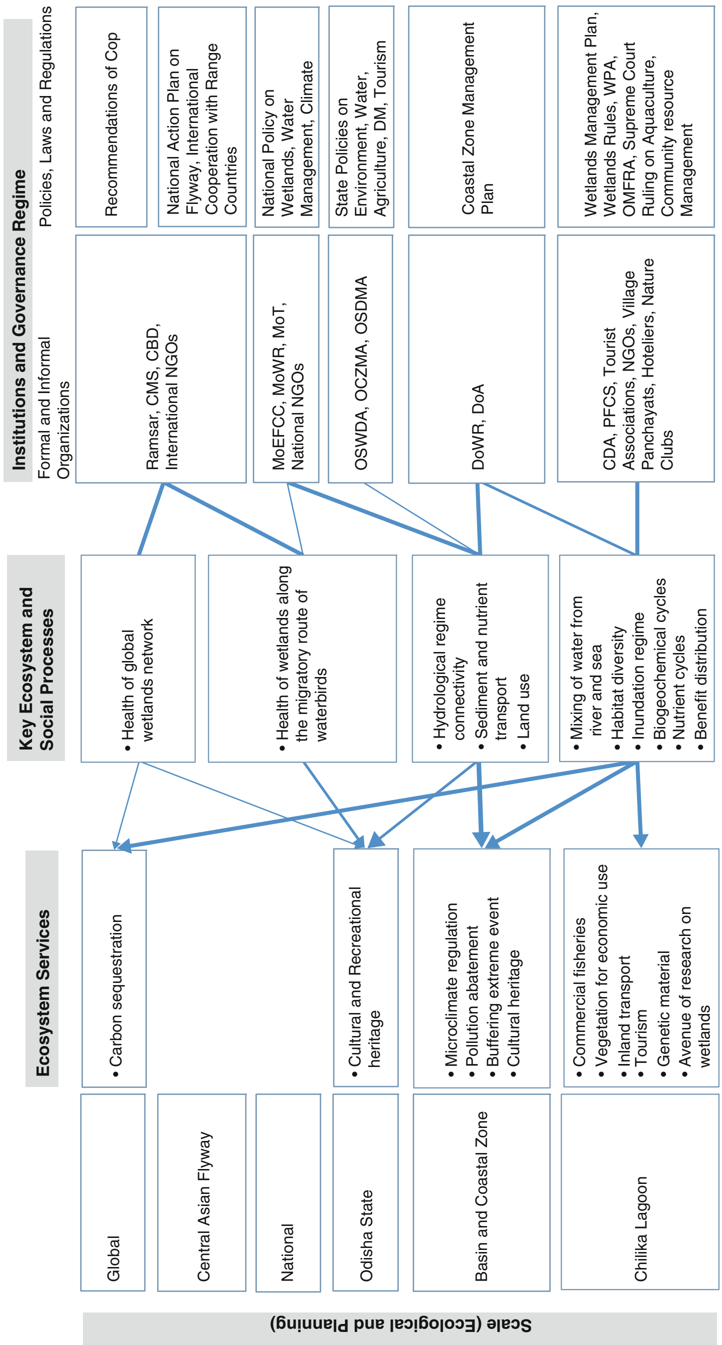

Fig 4.2 Chilika ecosystem services and institutions and governance regimes (Source: Authors)

probabilities of such changes, and leading indicators of thresholds (Carpenter et al. 2009; Steffen 2009) also needs to be developed as a priority.

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