Chapter 7

Agriculture in tropical river basins – impacts on aquatic lagoon and estuary ecosystems

OVERVIEW OF KEY CHARACTERISTICS

Tropical river basins contain both dryland and aquatic ecosystems that provide a rich environment and habitat for biodiversity, freshwater and saltwater fish and marine life, as well as forests and agricultural crop production, and livestock (to a lesser extent). They provide ample opportunities to exploit the provisioning services of both terrestrial and aquatic ecosystems, and have long attracted human settlement and use of the natural resources – in particular, for exploitation of forest resources, upland and irrigated agriculture, and fisheries and aquaculture.

The characteristics of sustainable interactions between agriculture and wetlands in the context of tropical river basins that discharge into rich and typical aquatic ecosystems at their estuaries (lagoons and deltas) are typically twofold:

- basin-level interactions between upstream agriculture and forestry use and their downstream impacts on the river and lagoon ecology;
- *in situ* and periphery exploitation of aquatic ecosystems and natural resources that infringe directly on the resilience and sustainability of the present state of the ecosystems.

Irrigated rice, which is generally a major agricultural activity within these tropical river basins (especially in Asia), has received substantial government investment and support to provide for the necessary water storage and conveyance infrastructure. As a result, large tracts in the river basins have been converted to irrigated rice cultivation, especially in the cases of Viet Nam and Sri Lanka. Primarily designed to expand and intensify rice production, these irrigated systems change the aquatic ecosystems in the basin through resulting modifications in water quantity (negative in the river flow, and positive in storage and lagoon drainage discharge) and quality (negative through pollutants and through diminishing salinity levels in coastal ecosystems).

Dryland agriculture, as well as forestry management and exploitation in the upper catchments of a basin, may substantially alter catchment runoff and water retention capacity. Irrigated development in the floodplain may affect river regime and water quality. Together, they may affect the coastal aquatic ecosystems through sedimentation of eroded topsoil and altered water inflows. In general, these transformations lead to changes in the flow regime of both the river and the water regime and quality in coastal

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* This chapter is based on work by: Lorenzen, Khoa and Garaway (2006); IUCN, Thua Thien Hue PPC and FAO (2006); Pattnaik (2005)

BOX 8

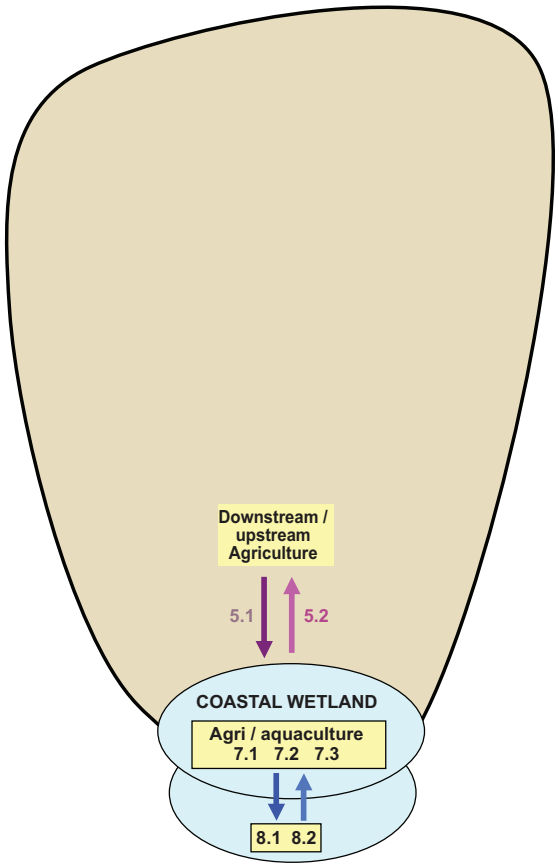
The issue of water quality in coastal aquatic ecosystems

Fisheries, irrigated agriculture and aquaculture in and around lagoons affect and are affected by the quality of the lagoon water in numerous and intricate ways:

- in the level of salinity (fresh for agriculture, specific level of brackishness for aquaculture; fluctuating levels of salinity for capture fish and lagoon species);
- in the refreshment rate at which aquaculture waste (pharmaceutical and solid) and agricultural waste (agrochemical) can be washed out;
- oxidation/eutrophication rates.

FIGURE 29

AWIs in tropical river basins and lagoons



lagoons and estuarine ecosystems. This often creates conflicts of interest between involved sectors over the quantity and quality of water resources.

In the past two decades, the aquaculture of shrimp and other marine species for commercial global markets has risen exponentially, especially in coastal brackish environments as provided by (tropical) lagoons. Aquaculture has a direct impact on the aquatic ecosystem by affecting both water quality and water circulation. Moreover, it is a productive system that imposes water quantity and quality standards often in direct opposition to those for the agricultural production systems. Aquaculture also has the potential to release exotic aquatic species into the environment that may compete for ecological niches with native species or be agents of disease and parasites.

The combined effects of agriculture and aquaculture systems often lead to severe transformations and degradation of the coastal aquatic ecosystems, especially through water quality changes (Box 8).

The fishery sector of both riverine and marine fish is also affected – positively in some locations and at some times, negatively in others. This is of particular social concern in this context as such fisheries are traditionally an important sector for the poor and landless to supplement both their income and food security (in particular, in terms of nutrients).

The involved sectors of agricultural crop production, fisheries and aquaculture have generally conflicting interests with regard to management of water resources (in quantity, timing and quality). These conflicts are played out both *in situ* (especially at the periphery of the coastal aquatic ecosystem) and at basin level, where upstream practices affect downstream uses. Figure 29 shows the main AWIs in this issue situation.

CASE STUDIES

The case studies used in this issue situation are those of:

- Chilika Lagoon – a coastal wetland, and designated Ramsar site, in India, that has been severely degraded owing to the combined impact of aquaculture and siltation resulting from expansion of agriculture and deforestation.
- Kirindi Oya Irrigation and Settlement Project in Sri Lanka, where irrigation development for paddy cultivation has taken precedence over other developments. This has created fish and aquatic ecosystem habitats through the creation of freshwater reservoirs and tanks. However, it has affected the salinity and marine species stocks in the coastal lagoon by increased freshwater drainage.
- Huong River Basin and Tam-Giang Cau Hai Lagoon in Viet Nam, which are characterized by priority development of irrigated paddy and a recent boom in shrimp cultivation in the lagoon, which has led to severe degradation of the aquatic ecosystem in the lagoon and serious problems of salt intrusion that even affect the freshwater supply to the city of Hue.

Similar issues concerning the interrelation between irrigated rice, fish and aquaculture and their impact on the state of aquatic ecosystem commonly emerge in other similar settings, especially in Asia (e.g. the Mekong Delta, river basins and catchments in Cambodia and the Lao People's Democratic Republic, and coastal Bangladesh).

Of these three cases, Viet Nam and Sri Lanka have strong similarities in that they share a strong history of purposefully-supported irrigated paddy development. These cases are discussed in Boxes 9–13. The case of Chilika is slightly different. It does not share this strong support for irrigated infrastructure development, and it is characterized by the impact of subsistence upland agriculture and forestry exploitation. Therefore, the case of Chilika is discussed separately and presented as the main case of this chapter.

DRIVERS

The most commonly shared and general driver is that of a steadily increasing population that is attracted to the rich natural resources of both the tropical river basin and its aquatic ecosystems (both inland fresh and coastal brackish) to support an increasing need for food security and to sustain economic livelihoods (Box 9).

In the catchment of the Chilika Lagoon, agriculture expansion and intensification has been driven primarily by population growth and associated needs of livelihood support and food security. The population living in the catchment

BOX 9

Drivers in tropical river basins and coastal lagoons

In the Huong River and Kirindi Oya cases, food security (through irrigated paddy rice development) has been the major driver to which the respective governments have responded. This has seen major investments in the development of irrigation infrastructure (storage and conveyance) for paddy cultivation in accordance with the "green revolution" agricultural development paradigm. In turn, this has led to more specific pressures such as agricultural intensification, agricultural colonization (actively supported by settlement policy in the case of Sri Lanka) and the general priority use of the available water resources for paddy cultivation.

In both cases, but especially in the Huong River case, the increasing global market demand for shrimps and other marine species has become an important driver of the recent boom in aquaculture in these coastal lagoons. In the Huong River case, this is actively supported by government policy directed towards the accession of Viet Nam to the World Trade Organization (WTO), which should further facilitate and support the access of Vietnamese aquaculture products (and others) to the world market. However, WTO accession in this regard does not necessarily lead only to further negative pressures through further intensification of the aquaculture sector. The more stringent international criteria for GAPs and the norms for food hygiene may in turn produce pressures for a transformation of aquaculture towards more sustainable, and less environmentally damaging, practices.

BOX 10

Pressures from urban water supply, irrigation and shrimp farming

In the case of Huong, the expanding city of Hue and its concomitant increasing demand for water supply and sanitation is increasing the pressure on the limited freshwater resources available in the dry season. Hue city, at the mouth of Huong River on the edge of the lagoon, is fully dependent on the Huong River water supply, which at times of low flow is affected by salt-water intrusion from the lagoon.

In both Huong and Kirindi Oya, the expansion and intensification of irrigated paddy rice constitute some of the major pressures on the river basin and coastal aquatic ecosystems. They have led to significant state changes in both the rivers and the lagoons. The water storage and conveyance infrastructure associated with irrigated rice leads to the specific pressures of water abstraction, conveyance and the consumptive and non-consumptive use by irrigated rice of the freshwater resources in the river. The historic and current priority allocation and objective of rice cultivation, along with the increasing population, is leading in both cases to specific pressures on the available water resources in the river basin. This is creating further demands for increased water storage and management capacity to enhance the intensification of rice cultivation (both in terms of increased cropping intensities and higher yields). In the case of the Huong River, this is leading to the expansion of the surface storage facilities through construction of new dams. In contrast, in the case of Kirindi Oya, the pressure is on changing the operational management of the reservoir (at the head of the system) and the tanks (within the command area of the irrigation scheme) to allow intensification of paddy cultivation in the dry season. In both cases, the pressure to intensify rice cultivation is leading to significant alteration of the freshwater flow regimes.

The exponential growth in shrimp and aquaculture in the Huong River lagoon is leading to intensified pressures on the available land and water resources – and direct competition with irrigated paddy. The agricultural polders at the fringe of the lagoon are being converted from paddy cultivation to aquaculture; whereas the prime concern for water requirements for aquaculture lies in the management of desirable levels of brackishness. The difficulty of managing this water quality aspect in aquaculture has led to a high incidence of disease and yield failure in aquaculture. In turn, this increases the pressure on the lagoon ecosystem as aquaculture expands further and encroaches into the lagoon in search of better water quality.

is about 0.8 million people, with about 0.2 million people around the lagoon). Agricultural development in the Chilika catchment, particularly within the Mahanadi Delta region, was enabled through an extensive channellization of the Mahanadi River floodplains, and the construction of a series of hydrological structures to enhance water availability for agriculture. However, designation of the lagoon as a Ramsar site enabled significant investment into conservation measures in order to conserve the ecological character of the systems as well as to restore the livelihood resource base of the communities. Nonetheless, agricultural development has taken place, primarily in two forms in the catchment of the lagoon:

- cultivation of cashew, which is driven directly by market demand and opportunity;
- cultivation of rice, which is driven primarily by subsistence or transition (semi-commercial) agricultural livelihoods.

Analysis of this situation shows that there are two principal drivers that lead to the possibly unsustainable use of forest resources in Chilika: (i) the cashew market, which leads to pressures of deforestation for cashew plantations; and (ii) the consumption of fuelwood by households in the catchment.

The lagoon fishery comprises capture and culture sources, traditionally managed by the communities. However, food and nutritional security needs have been the key drivers of the fisheries. The introduction of shrimp farming on the fringes of Chilika as a part of a poverty alleviation package led to rampant expansion of shrimp cultivation within the lake. This also brought non-fisher communities into fishing within the lake, creating a nexus of profit-driven, capital-intensive, moneylender-trader

systems, with severe conflicts with the traditional fishers. The expansion of aquaculture was further fuelled by devaluation of the local currency and export liberalization policies. Conversion of agricultural fields within the delta for shrimp culture has also been attempted but with limited success (and resulted in long-term soil degradation and conflicts).

BOX 11

State changes – hydroecological degradation in lagoons

In the Huong River, the reduction in water circulation and the refreshment capacity is caused primarily by: (i) colonization of the lagoon by aquaculture; and (ii) reduced freshwater outflow into the lagoon in the dry season from both the river and the agricultural polders. (A negative hydraulic gradient in the dry season leads to salt intrusion in the river, polders and groundwater table). The decreasing water quality in the Huong Lagoon is undermining the productivity and sustainability of agriculture and aquaculture, while natural aquatic habitats are being colonized by aquaculture in search of "fresh" (non-stagnant) water.

In the case of Kirindi Oya, the state changes are different and primarily two-fold:

- The expansion and intensification of irrigated paddy has led to an increase in diffused drainage of freshwater into the lagoon. This affects the brackishness of the lagoon by reducing salinity levels, and hence the ecological habitats and fish stocks it can support.
- In the initial stages of Kirindi Oya, the new reservoir and tanks created new aquatic freshwater habitats for fish stocks and aquatic species. Biodiversity thrived in these so-called "human-made wetlands". However, in the present stage of further intensification of irrigated rice, these freshwater habitats are threatened by excessive drawdown in the dry season. This may not only threaten fish stocks and other aquatic species numbers, it may also undermine the resilience of the system.

PRESSURES

Agricultural expansion in the upper catchments of the Chilika Lagoon for subsistence agriculture and transitional market-oriented agriculture (rice, upland food crops and cashew) is leading to increased pressures on available land and water resources in the catchment. The transformation of forestry and upper catchment areas into cashew plantations is causing the forest resource base for traditional homestead fuel consumption to dwindle, exacerbating the pressure on forestry resources. At the same time, the relatively low yields of rice and upland crops lead to further expansion of agricultural areas in the catchment, at the cost of natural vegetation, in order to satisfy food and livelihood requirements.

In Chilika Lagoon, the capture and aquaculture pressures on the ecosystems have primarily become an issue as a result of the state changes of the ecosystems (mainly siltation of the mouth leading to a progressive shift to a freshwater-dominated system with comparatively lower biodiversity) and their diminishing carrying capacity of fish stock, that is sought out by an ever increasing human population.

STATE CHANGES

The Chilika aquatic lagoon ecosystems have undergone severe degradation and shifted into a seemingly vicious cycle of further degradation and diminishing resilience of the lagoon ecosystem. The state changes that have caused these developments are primarily excessive silt deposition in the lagoon from erosion in the upper catchment as a result of poor agricultural and forestry management practices. The siltation has led to decreasing water circulation and refreshment, which is further exacerbated by nature as it leads to a boom in aquatic weeds. The situation has been compounded by the effects of long-shore drift and the increased sediment levels that have limited the outlet of Chilika to the sea and so led to reduced salinity levels. Overall, these changes in the lagoon environment have led to a transformation in the ecological habitats in the wetland, especially a "sweetening", or salinity reduction, of the brackish environments, and to dwindling fish stocks and species diversity.

BOX 12

Competition and economic diversification impacts of shrimp cultivation

Shrimp cultivation and aquaculture tend to lead to increased competition for and conflicts over coastal land and water resources as they create opposing demands on water quantity and quality compared with that of, in particular, irrigated rice cultivation. Segregation and polarization of these sectors, and their respective practitioners, are common features with an increased incidence and intensity of conflicts – sometimes even violent (as in Bangladesh and the Philippines). The situation is exacerbated by water management and governance structures that are traditionally centred around, and supportive of, irrigated agriculture. Shrimp culture and aquaculture tend to be individual entrepreneurial activities that affect and "free-ride" the water management arrangements of agriculture. Early adopters of shrimp culture and aquaculture quickly form a new wealthy economic class, which enables them to increase their enterprises.

In Huong, the shrimp and aquaculture business has gone beyond the economic boom stage. The present state of degradation of the lagoon is affecting the aquaculture sector significantly, leading to a sharp fall in yield and economic failure among enterprises. Thus, the state and fate of aquaculture in Huong is becoming an issue that may open up opportunities for common-resource-pool management strategies in the aquaculture sector, and links with the rice irrigation and city water management structures and strategies.

IMPACTS

The impacts of state changes in the Chilika situation include a decline in the yields from the subsistence and semi-market (transition) agriculture in the catchment as a result of soil erosion. As a consequence, households are prone to shocks of food and economic insecurity that tend to lead to further extensification (i.e. low input–output) of agricultural practices as they no longer possess the means to invest in GAPs. The increasing scarcity of fuelwood tends to have a similar impact in that it erodes the household livelihood base as more time and resources need to be diverted from productive activities towards securing household fuel. In the wetland, fish yields have declined while the competition for fish, both as a primary livelihood source and dietary supplement, has increased. Declining catches have eroded the livelihoods of fisher folk as well as food and nutrient security of the poor.

The trade-off between increased competition by agriculture and aquaculture for restricted land and water resources is usually the environment and the fish stocks of the inland and coastal waters. The landless and poor, those most dependent on these provisioning services, are the worst affected by a substantial loss in food security and livelihood provisioning. This trait is particularly evident in this Chilika case.

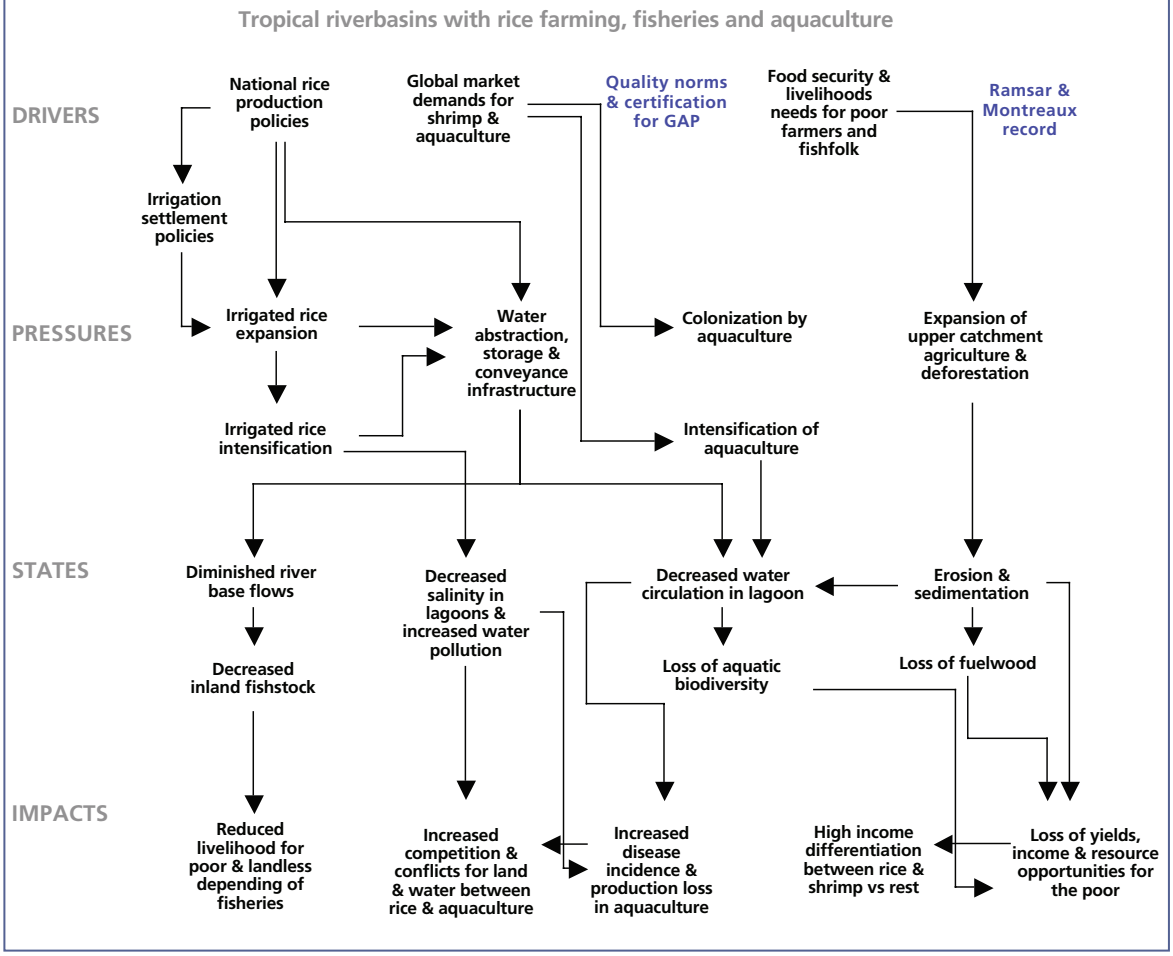
RESPONSES

A comprehensive restoration and conservation programme has been initiated in response to the drivers, pressures and state changes operative in the lagoon and its catchment. This has been driven to a large extent by the inclusion of the Chilika Lagoon in the Montreux Record of endangered Ramsar wetlands, and the resulting political and financial support provided by the government to take Chilika off this list.

The comprehensive multiple-response strategy is directed towards different elements of the drivers, pressures, state and impacts that have been affecting the Chilika Lagoon, its catchment and its population (Figure 30). This strategy includes:

- Establishment of the Chilika Development Authority to develop and provide integration and regulation for the common-pool management strategies, and to provide support and training for community-based natural resources use and management.
- Restoration of the lagoon hydrology by dredging a new outlet to the sea. In combination with other measures, this has led to a marked improvement in water

FIGURE 30
DPSIR linkages in tropical river basins (including lagoon ecosystems) with rice farming, fisheries and aquaculture



circulation, recovery in brackishness, reduced weed infestation, and increased fish and marine stocks (and subsequent fish landings by fishers).

- Community-based catchment development and management plans. These are directed towards:
  (i) sustainable agriculture and forestry management practices that reduce erosion and siltation; and
  (ii) food and income generation for subsistence agriculture and cashew growing.
- Reforestation and forest management in the catchment.
- Development and dissemination of fuel-efficient stoves that reduce the demand for fuelwood.
- Food processing and natural product processing and marketing programmes that enhance the livelihood means and opportunities of the agriculture and fisheries communities.
- Development of ecotourism in the lagoon as a supplementary economic opportunity of the aquatic ecosystem.

CONCLUSIONS

The cases in this chapter show how catchment, or upstream activities, interact with coastal lagoon ecology, the capture of inland and coastal fish, and how aquaculture

BOX 13

Water management responses to integrate fish/ aquaculture with rice cultivation

The immediate response in the Huong River case has been limited to a classical water supply management strategy, and directed towards increasing the surface storage capacity of Huong River infrastructure. The extra available water in the dry season is to be directed towards: (i) hydropower; (ii) intensified rice cultivation; and (iii) ecological base flows. In addition, a salt intrusion barrage will be constructed to protect the dry-season freshwater supply to the city of Hue, and the sea outlet of the lagoon will be enlarged to increase water circulation in the lagoon. The integration of water management for agriculture, ecosystems and aquaculture is in its infancy, and primarily directed towards establishing governance and regulation structures. The former is being achieved by creating a cross-sectoral and interdepartmental Huong River Management Board. The latter is being sought by attempting to regulate the further expansion of aquaculture into the lagoon. However, future responses may be directed towards achieving higher water-use efficiencies and productivity in the irrigated rice sector, and transforming aquaculture into an industrialized closed-culture system that does not affect the water quality and hydrology of the lagoon and conforms to the high quality and environmental standards of GAPs.

In Kirindi Oya, a first step has been taken towards an integrated and participatory approach to devising a water management strategy that will explicitly serve the multiple purposes of rice cultivation, inland and coastal fisheries, and sustenance of aquatic ecosystems. The immediate objectives are to establish minimum water-level management targets for the reservoir and tanks in the dry season (ones adequate to support fish stocks and serve as dry-season harbours for aquatic species). This is to be accompanied by improved water management and agronomic practices that enhance water-use efficiency and productivity within the irrigated rice scheme, and reduce the drainage outflow of excess freshwater into the lagoon.

affects and interact with both lagoon ecology and upstream water uses and users. They also highlight how different agricultural/aquacultural activities are intrinsically linked to different stakeholders and livelihoods, and where emerging trade-offs between provisioning services usually represent socio-economic trade-offs between livelihoods and between sectors. The propensity for these trade-offs to spiral into negative feedbacks, which further increase the pressures for provisioning services, is high for these systems. In turn, this will lead to degradation of the ecological state and undermine the sustainability of the provisioning services, both agriculture and aquaculture. Tackling these negative feedback loops in an attempt to rebalance the ecosystem services by at least reinvigorating the non-provisioning ones will thus require a concerted response at multiple scales, considering the multiple factors and agricultural domains of the river basin that includes the lagoon ecosystem. The response strategies deployed in Chilika and conceived in the Huong and Kirindi Oya basins show these characteristics in which multiple targeted responses are directed towards the diverse provisioning services being used, and the stakeholders that depend on them. The majority of the individual responses are still technical in addressing specific pressure–state–impact relations by means of promoting GAPs that both improve productivity and livelihood, as well as the interaction of the particular agricultural, fisheries and aquacultural practices with the wetland ecosystem. However, as the Chilika case illustrates, deploying a multitude of these practices can be an effective measure to improve the overall state of the ecosystem and tackle negative feedback loops.

Reinvigoration of the non-provisioning services is being actively pursued in these cases at state level, where wetland restoration and improvement measures are being implemented. Moreover, Chilika is addressing the pressure level specifically with improvements in the agricultural processing (and thereby income and thus impact), and by exploitation of the cultural services through ecotourism. While the driver level has

not been much addressed specifically, the DPSIR analysis of the Huong and Chilika cases has indicated how positive drivers (such as the certification rules for shrimp and the Montreux Record, respectively) may be (or become) important catalysts for positive responses.