INLAND FISHERIES – TEEBAGFOOD

[EXECUTIVE & POLICY MAKERS' SUMMARY]

Ecosystem services in freshwater fish production systems and aquatic ecosystems: Recognizing, demonstrating and capturing their value in food production and water management decisions

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- **Lower Mekong Basin** case study: Rattanawan (Tam) Mungkung, Ratcha Chaichana and Santi Senglertsawai, Kasetsart University, Thailand
- **Lake Victoria** case study: Dismas Mbabazi and Oliva C. Mkumbo, Lake Victoria Fisheries Organisation, Uganda and Cecile Brugere.

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Disclaimer

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EXECUTIVE SUMMARY

The study

The study developed a holistic assessment of different production and management scenarios in the inland capture fisheries and freshwater aquaculture sectors taking into account the (hidden) impacts, externalities and dependencies between fish production, environment and social and economic systems, and examining the full range of ecosystem services and trade-offs arising out of the use of aquatic ecosystems. The study took stock of the current state of knowledge on the multiple services (benefits) that fish production generates, globally and in three case studies in **North America** (Columbia River, CR), **Asia** (Lower Mekong Basin, LMB) and **Africa** (Lake Victoria Basin, LVB). The case studies provided an analysis of the economic value of the provisioning, regulating, supporting and cultural services of inland capture fisheries and freshwater aquaculture under existing and alternative water management scenarios. This allowed for quantifying the changes in ecosystem services values arising out of management alternatives.

The main ecosystem services considered in each system were: (i) food production (animal proteins and nutrients); (ii) water quality; (iii) biodiversity; (iv) carbon fixation and greenhouse gas emissions; (v) nutrient cycling; and (vi) income and livelihood support. Other ecosystems services were included where important.

The ecosystems in the case studies support a wide array of ecosystem services. Fish production – through commercial capture, tribal, recreational and small-scale capture, as well as through aquaculture, is one of the most important provisioning services of these ecosystems. However, fish production is in competition with other water uses and management practices that seek to satisfy other development objectives and other needs. Key competitors are hydropower generation (CR and LMB) and use and transformation of wetlands (LVB) for agriculture and urbanisation. The case studies demonstrates significant trade-offs between fish production and the other uses of these aquatic ecosystems. Thus, externalities generated by hydropower generation and the unsustainable use of wetlands are substantially affecting the benefits derived from the fish production service in all cases.

The total value of fish production is estimated at: US$4.85 billion per year for the Mekong River Basin (riverine and reservoir capture fisheries and aquaculture), US$846.9 million per year for the Lake Victoria Basin (Nile perch, other fisheries and cage aquaculture), and US$107 million per year for the Columbia River (ocean and river commercial fishery, tribal fishery and recreational fishery).

The **Columbia River**, **Lower Mekong Basin** and **Lake Victoria Basin** ecosystems supported a wide array of ecosystem services. Fish production – through commercial capture, tribal, recreational and small-scale capture, as well as through aquaculture, was one of the most important provisioning services of these ecosystems. However, fish production was in competition with other water uses and management practices that seek to satisfy other development objectives and other needs. Key competitors were hydropower generation (CR and LMB) and use and transformation of wetlands (LVB) for agriculture and urbanisation.

Scenario analysis suggested that, in the Lower Mekong Basin, if the construction of all mainstream dams proceeds as planned, it was estimated that the fish catch will decrease by 340 000 tonnes annually, suffering a loss valued at a more than US$476 million per year. This does not include the negative impacts this will have on the productivity of coastal and delta fisheries, which are also likely to be significant. Gains from newly created reservoir fisheries (but excluding aquaculture), though expected to be worth US$14 million per year, would far from compensate the losses incurred. This was particularly important from a nutrition point of view as the amount of protein at risk of being lost annually represented 110 percent of the current total annual livestock production of Cambodia and Lao PDR.

Current management of the Columbia River includes many improvements for fish conservation. However, the scenario returning hydroelectric energy generation to past levels would have resulted in a deficit in net social benefits of US$332 073 per year from cultural/subsistence fishing, US$961 861 million per year from commercial fishing and US$1.3 million per year from recreational fishing compared to the benefits obtained from these fisheries under the current management regime. Scenarios prioritizing water resources conservation over development were shown to bring about many social benefits. In the Columbia River, where recreational fisheries is the most valuable ecosystem service, conservation would have increased benefits to society by about US$3.3 million per year, compared to an annual loss of US$2.6 million if hydropower development was prioritised.

Wetland conservation also has an important regulating role in fisheries. For example, in Lake Victoria, the values of their regulating services were shown to be substantial and comparable to the value of provisioning services (food). Thus, the planned conversion of wetlands to agriculture would require payments of 35 percent of the value of crops to farmers in the area to compensate for the natural nutrient buffering service formerly provided by the wetlands.

Fish production systems also support nutrient cycling. For example, anadromous salmonids swimming up to spawn after accumulating most of their adult body mass at sea, contributed to the cycling of nutrients from the ocean to areas far inland. In the Columbia River Hydropower, prioritization would result in a *net* loss of US$2 977 per year for the entire river compared to the current water management scenario. However, if the river were to return to pristine conditions, there would be a *net* social benefit of US$16 633 per year from nutrient imports by the salmon compared to current management scenario.

Fishers and fish farmers exploit aquatic ecosystems for fish, but are also in many ways the custodians of the fisheries and aquaculture systems in their care. Affecting one has repercussions on the other and vice-versa. Within the confines the three case studies, a profile of winners and losers from water management and development priorities emerged. In the Columbia River, losers from water development priorities were recreational fishers and the ecological and economic value of the recreational fishery in their custody. In the Lower Mekong and Lake Victoria Basins, losers were the local communities of small-scale fishers and non-fishing poor households whose part or entire livelihoods and wellbeing depend upon the health and good functioning of these aquatic ecosystems.

Inland aquatic ecosystems and the associated communities using and dependent on them were shown to be extremely complex. Complexity is further increased by the transboundary nature of aquatic ecosystems and their resources (fisheries, water), which raises great challenges with

regard to their management and may not be encountered to the same extent with other food production systems.

Scaling up the findings of the case studies to a continental scale is extremely challenging. Underestimation is certainly the case for the fish production systems, owing to under-reporting of the catches and to gaps in the valuation approaches used. On a continental scale, the value of the regulating services of fish production systems and aquatic ecosystems appeared most valuable, ahead of provisioning services, and that the value of cultural services was approximately of equal importance to that of supporting services.

Key messages

1. Considering inland fisheries and freshwater aquaculture production systems from an ecosystem services lens is useful.
2. Inland fisheries and freshwater aquaculture provide much more than fish.
3. The value of inland fisheries and freshwater aquaculture is under-estimated.
4. Water management decisions need to recognize and encompass the services supplied by both aquatic ecosystems and inland fisheries and freshwater aquaculture.

Policy recommendations

- Include all ecosystem services and all sectors using the ecosystem in planning, developing and managing freshwater aquatic ecosystems.

- Modelling of ecosystem services in a variety of ecosystems and sociocultural contexts should become standard practice for the formulation of policies concerning the maintenance and enhancement of inland fisheries and freshwater aquaculture's services.

- International policies and laws supporting the rights of indigenous people should be adopted and implemented at national and more local levels.

- Management of aquatic ecosystems must include the sustained supply of *all* their services by adopting an ecosystem approach. These efforts need to be pursued and strengthened at national levels and in transboundary water basins and should be given due recognition in high-level policy arenas. Key to this is the development of institutions capable of cross-sectoral integration.

- More commitment of will and finances should be devoted to address the lack of basic data on inland capture fisheries catches and demonstrate the important role the sector plays in supporting livelihoods, nutrition and food security, economic development and wellbeing.

POLICY MAKERS' SUMMARY

Ecosystem services are the benefits provided by ecosystems to humans. A widely accepted categorization of these benefits is whether they are **provisioning**, such as food, water, timber, genetic resources, **regulating**, such as regulation of climate, floods, water quality, **supporting** such as soil formation, nutrient cycling and pollination, or **cultural**, e.g. spiritual fulfilment, aesthetic enjoyment and recreation.

The following summarizes the material found in the full report.

Key messages

1. **Considering inland fisheries and freshwater aquaculture production systems from an ecosystem services lens is useful.** The TEEB/Ecosystem services approach to inland fish and freshwater aquaculture production enables shifting emphasis away from the traditional, neo-classical economic production perspective of fisheries and aquaculture, to an ecosystem one in which relationships and dependencies between coupled social/economic and natural systems are examined and the wider range of linked ecosystem-human benefits and losses is holistically embraced.

2. **Inland fisheries and freshwater aquaculture provide much more than fish.** Inland fish production from either capture or culture generates fewer trade-offs and negative externalities on the delivery of other ecosystem services than other sectors generate on it. Overall, fish production allows the delivery of many other ecosystem services besides fish itself. Fish production furthermore greatly enhances the supply and value of the other services from aquatic ecosystems. As such, fish production should be considered as a form of "restoration of natural capital"[1], i.e. as an investment in and replenishment of natural capital stocks to increase flows of goods and services from aquatic ecosystems.

3. **The value of inland fisheries and freshwater aquaculture is under-estimated.** Despite its importance, the value of freshwater fish production, in conjunction with the value of healthy aquatic ecosystems within which it takes place, remains under-estimated in the three case studies. This is symptomatic of freshwater ecosystems around the world and a significant reason for their demise. This value could be increased and ecosystems better protected if the values, including non-monetary values, of all the services fish production and aquatic ecosystems supply were more accurately quantified.

4. **Water management decisions need to recognize and encompass the services supplied by both aquatic ecosystems and inland fisheries and freshwater aquaculture.** The 'non-provisioning' ecosystem services of inland fisheries and freshwater aquaculture are extremely valuable and often overlooked in development decisions. Trade-offs usually only consider the provisioning services of different ecosystem management scenarios. For example analysis of draining wetlands usually only considers the loss of fish production and not the water purification aspect of the regulating ecosystem function. In light of the large trade-offs that result from the modification of aquatic ecosystems for water use, assumptions behind the benefits

[1] Aronson et al. 2010.

generated by water resources development such as hydropower and irrigation need to be more critically scrutinized and questioned. Scenarios prioritizing many commercially important water development objectives create large negative externalities on fish production systems that are already weakened from poor management and overfishing (within the sector) and other ongoing externally imposed anthropogenic pressures.

The study

This study was part of a larger project, *The Economics of Ecosystems and Biodiversity (TEEB): Natural Resource Accounting at country-level and across specified industrial sectors,* and focused on the role **inland capture fisheries** and **freshwater aquaculture** production systems play in the supply of these services, regardless of their form, scale and intensity. The study encompasses all freshwater aquatic environments such as lakes, reservoirs, rivers and streams, and other wetlands (e.g. swamps, floodplains), whether they are man-made (e.g. reservoirs) or natural (e.g. unregulated rivers). In 2005, the Millennium Ecosystem Assessment revealed that capture fisheries and fresh water were used "well beyond levels that can be sustained even at current demands, much less future ones".

Freshwater fish is vital in the livelihoods and nutrition of many of the rural poor. Recognizing, capturing and valuing the importance and contribution of inland fisheries and freshwater aquaculture to ecosystems health and human wellbeing is fundamental to safeguard their future. However, this value is often un-noticed and not included in water resources development agendas.

Additionally, this value is usually underestimated, although the actual contribution of inland capture fisheries to the livelihoods and food security of poor and rural communities in the developing world is massive. The majority of farmed fish comes from inland waters (64%[2]), representing 56% of the value of the total quantities produced by aquaculture in 2013. Aquaculture is expected to fill the overall decline in fish supply from capture fisheries and to play a major role in helping meet the nutritional needs of a growing world population, provided production systems' efficiency keeps on improving and policies supporting the growth of the sector move beyond the economic development – environmental conservation dichotomy.

Self-generated externalities of capture fisheries (through overfishing) and aquaculture (through pollution and habitat destruction) have plagued the sustainable development of both activities and hampered their full contribution to human wellbeing, whilst – justifiably – soiling their image among the wider public. Yet recent efforts at international and national levels promoting the implementation of ecosystem-based approaches to management have contributed to redress the development trajectory of both sectors.

However, in order to fulfil the full range of ecosystem services these efforts need to be complemented by efforts from other economic sectors, such as hydropower and agriculture, which compete for the same aquatic resources and whose impacts on fish production are rarely compensated.

[2] Excluding aquatic plants.

Inland capture fisheries: unique and special, yet invisible

Asia and Africa are the main producing continents with almost 92% of the production of freshwater fish. This represented 11.7 million tonnes landed from inland capture fisheries globally in 2013, but only 13% of the total quantities landed in both marine and inland waters[3]. This is an underestimate of the true landings as a significant portion of the catch goes unreported due to the informal nature of the activity. In developing countries, the widespread nature and high level of subsistence fishing confounds the reporting of catch figures by authorities. In industrialized countries, where recreational fishing is the dominant or sole use of most freshwater fish populations, recreational fisheries are seldom reported in official statistics, which tend to focus on commercial landings.

The bulk of inland capture fisheries' catches, global value and use for domestic consumption comes from small-scale operations. It is estimated that small-scale inland capture fisheries employ 60 million people directly and indirectly around the world, against 1 million for large-scale, commercial fisheries. Fishing is generally carried out as a mainstay or supplementary livelihood activity in which men and women equally participate. Discards are insignificant as most of the fish caught is consumed locally, providing an important source of protein and crucial nutrients in often poor and remote communities. Between 118 and 700 million people participate in recreational fisheries globally. Although mostly in industrialized countries, this trend has started to spread to economies in transition.

The bulk of the estimated production from **lake and reservoir capture fisheries** comes from small-scale fishers in developing countries and recreational fishers in industrialized countries and this is seldom recorded in official statistics. Selective fishing or overall high fishing pressure is threatening lakes and reservoirs' biodiversity but are not the sole anthropogenic drivers of change. The stocking of water bodies is increasingly popular in Asia as a remediation measure though the introduction of fishes can affect ecosystem functioning, community structures and genetic integrity. **Culture-based fisheries** can also raise issues in terms of reporting: some countries report catches under 'aquaculture' (e.g. China), others as capture (e.g. Mexico) and this has major implications for the management of the concerned water bodies.

Riverine fisheries are dependent on riverine fish populations that are, in contrast to lake fish populations, migratory, longitudinally (along the river), laterally (from river into surrounding wetlands) or from rivers into the sea where they can sustain a substantial fishery (e.g. salmon). Stocking is also a common practice in river systems, both to mitigate the effects of hydropower development (e.g. salmon) and to strengthen threatened populations (e.g. Mekong giant catfish). Riverine fisheries are also important for recreation in temperate regions and unique in the way they provide cultural and social services.

Inland capture fisheries are facing two critical issues. First, they are threatened by pollution, damming for hydropower generation and irrigation, and draining wetlands for development, which all degrade freshwater habitats despite the ecological, economic and social importance of these. Second, their main provisioning service – fish catches – are under-reported in national statistics. As the market price of sold fish reflects only the direct use value of the fisheries, the full value of these fisheries and the importance of their role in the economy, livelihoods and maintenance of ecosystems, is underestimated. Consumer and producer

[3] Excluding aquatic plants.

surpluses have been estimated for a number of individual commercial, recreational and subsistence/ artisanal fisheries, but on an ad-hoc basis, which constrains extrapolation of these values to other fisheries. Together these factors result in the lack of visibility of inland fisheries in natural resources management and development decisions, and explain why inland fisheries are most threatened by the modification of aquatic habitats.

The growing importance of freshwater aquaculture

Freshwater aquaculture systems offer a wide range of options to produce fish. Freshwater aquaculture takes place in ponds constructed on land and in natural aquatic habitats (lakes, reservoirs and rivers). In 2012, a total production of 42 million tonnes was reported; the bulk of this production is cyprinids (carps) and cichlids (tilapia) and other freshwater fish. Today 93% of the world's freshwater aquaculture production comes from Asia, following a rapid increase in production in the last 30 years.

Freshwater aquaculture can take many forms. **Cages**, typically sited in larger water bodies such as lakes and reservoirs, offer flexibility in the choice of locally-available materials. Negative impacts caused by freshwater cage aquaculture, such as pollution and conflicts over space, are as dependent on the style of management and farming as on prevailing ecological and hydrological conditions. **Pond aquaculture** is the most widespread aquaculture system and varies widely in design, scale and intensity. Pond aquaculture generate many services and contribute significantly to the income and nutrition of millions of small-scale farmers, in particular in Asia. Their environmental impacts relate essentially to risks of water pollution through release of pond effluents, and threats to biodiversity depending on the land area used, the species used (exotic or not) and overall management of the activity. Pond aquaculture can also be a large consumer of water despite its potential for integration with other food producing activities. **Rice-fish farming** is traditionally found in China, and is making a steady contribution to inland aquaculture production. It generates many positive and significant ecological and human benefits. The intensification of rice production is however constraining the practice.

Overall, the environmental impacts of freshwater fish production systems around the world are unclear, owing to the multiplicity of factors that combine to create or mitigate such impacts. Typically, freshwater extensive and semi-intensive aquaculture systems have a lesser effect over a greater area, while intensive systems usually have a more severe but more localized effect. In general, freshwater aquaculture is carried out on a small scale and found to improve human wellbeing and equity, thanks to the generation of benefits greater than those associated with locally available land farming alternatives. Freshwater aquaculture products are primarily destined domestic markets, and therefore a critical element in the food security of producers and local consumers. Cultured catfish and tilapia, however, have become two commercially important freshwater species on global markets and are largely exported to Europe and the United States.

Statistics of production are more reliable for aquaculture than for inland fisheries and show the continuous growth of the sector. However, the other non-provisioning benefits of freshwater aquaculture, such as the supporting services of water retention, carbon sequestration and nutrient recycling, are under-studied. Consequently, and similarly to inland capture fisheries, market prices of aquaculture products do not fully capture their contribution to ecosystem and human wellbeing, and the trade-offs resulting from ill-informed development decisions are hampering the sustainable development of the sector.

A framework for assessing the ecosystem services of freshwater capture fisheries and aquaculture

We conceptualise fish as both a living stock of natural capital and as a product of aquatic ecosystems. Capture fisheries and aquaculture are major mechanisms through which benefits from aquatic ecosystems are extracted. From the stock of natural capital (the 'fishery') flow some benefits (e.g. fish as food) with human intervention (e.g. fishing effort). Other benefits can flow without human intervention: fisheries also fulfill a number of functions as part of the ecosystems they are embedded in, and are behind the delivery of non-provisioning ecosystem services, such as nutrient transport and pest control.

Similarly, farmed fish stocks are a form of 'cultivated natural capital' yielding a flow of services over time. To harness these services (e.g. as fish products for food or other uses), human intervention is required in the form of labour, physical inputs and knowledge. Yet, other non-provisioning services can occur simultaneously without human intervention, such as ponds acting as carbon sinks and groundwater recharge. Considered as an integral part of aquatic ecosystems, fisheries and aquaculture production systems therefore contribute to the supply of many other non-provisioning services such as regulating (nutrient cycling), supporting (habitat maintenance) and cultural (recreation) services. Both fish production systems can also generate negative impacts and self-imposed externalities, as with overfishing in the case of capture fisheries.

Tables 1 and **2** highlight the services and 'disservices' that inland capture fisheries and aquaculture production systems generate. Overall however, the nature of these services – and even more so their value – have been under-studied, which contributes to their lack of visibility in water management decisions.

Table 1: Provisioning, regulating, supporting and cultural services from freshwater fish populations and inland capture fisheries. + Positive contribution, – Negative contribution or self-inflicted impact, +/- Mixed contribution.

Provisioning	+/-	Regulating	+/-	Supporting	+/-	Cultural	+/-
Proteins and other nutrients	+	Nutrient cycling	+	Biodiversity	+/-	Recreation and tourism	+
Medicinal products	+	Biological regulation	+	Food webs and trophic structures	+/-	Education	+
Income/revenue	+	Sedimentation regulation	+	Ecological balance	+/-	Research	+
Aquafeeds	+	Water quality	+	Aquaculture	+	Cultural and spiritual identity and heritage	+
Jobs, livelihood options	+						
Health, food security	+						

For further information on the nature of these services and sources, please refer to Part 1 of the report.

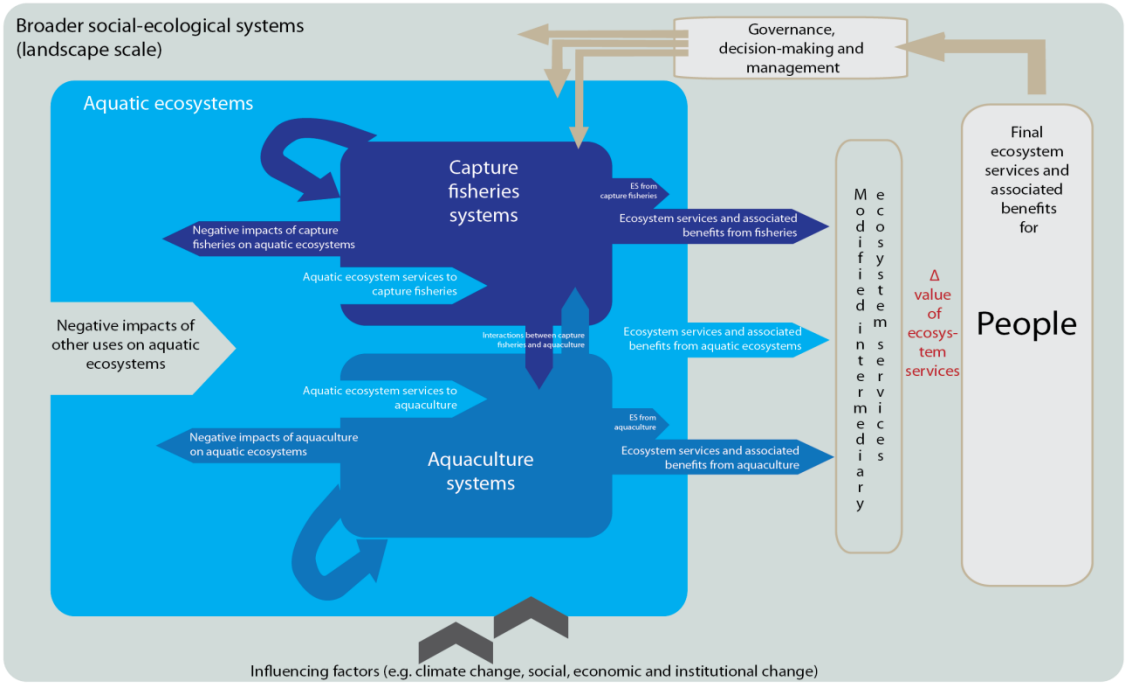
Table 2: Provisioning, regulating, supporting and cultural services from freshwater aquaculture.
+ Positive contribution, – Negative contribution or self-inflicted impact, +/- Mixed contribution.

Provisioning	+/-	Regulating	+/-	Supporting	+/-	Cultural	+/-
Proteins and other nutrients for human consumption	+	Nutrient cycling	+/-	Biodiversity	+/-	Prestige	+
Income/revenue	+	Biological regulation	+	Land-based crop production enhancement	+	Education	+
Jobs, livelihood options	+	Groundwater recharge	+/-			Research	+
Health, food security	+	Carbon fixation	+			Cultural heritage	+
Fingerlings as bait for capture fisheries	+	Local temperature regulation	+			Community cohesion	+

For further information on the nature of these services and sources, please refer to Part 1 of the report.

The relation between fish production and freshwater aquatic ecosystems is summarised graphically in the conceptual framework presented in **Figure 1**. This framework captures the interactions of inland capture fisheries and freshwater aquaculture systems with aquatic ecosystems through the use and supply of ecosystem services. It also reflects the fact that human interventions, through improved governance and decision-making, needs to adequately account for the value to people of aquatic ecosystem services flowing through fish production systems. This in turn has positive impacts on the flow of services to and from capture fisheries and aquaculture for the benefit of people and nature. In this context the relative importance of the ecosystem services will vary depending on which aquatic ecosystem is studied (e.g. lakes, reservoirs, rivers, floodplains, swamps and rice fields).

Figure 1: Linkages between fish production, ecosystem services and governance. (Based on WLE (2014)[4].



[4] WLE - CGIAR Research Program on Water, Land and Ecosystems (WLE) (2014) Ecosystem services and resilience framework. International Water Management Institute (IWMI), Colombo. doi: 10.5337/2014.229.

Trade-offs and externalities

Trade-offs and externalities can take place within fish production itself. In the case of fisheries, such self-inflicted harm occurs through overfishing. In the case of aquaculture, externalities created by unsustainable aquaculture practices are often self-inflicted by farmers, e.g. spread of disease among farms. They jeopardize the environment and the viability of their own enterprises and the long-term production of fish – the very provisioning service aquaculture systems are supposed to fulfil. For example, over-harvesting to increase fish catches depletes fish populations, alters food chains and biodiversity and contributes to a shift to smaller species and individuals. In efforts to reduce the use of forage fish in fish feeds, land-based crops such as soybean are increasingly being used as feed ingredients. Although this reduces the use of wild fish in diets, it puts increasing pressure on freshwater resources that are required to produce crops used for both feeding fish and people.

Similarly, the introduction of exotic species to increase yields (e.g. in reservoir or enhanced capture fisheries), or to reduce the risk of disease infection and spread and maintain yields (e.g. pond or cage aquaculture) can result in changes in biodiversity, food chains, production and nutrient cycling. Such practices threaten in their wake the social-ecological systems that have co-evolved with the adaptation of humans to their natural environment. As these externalities remain uncompensated, they are adding to other drivers of change, such as climate change and increased water withdrawals, in changing the landscape and functioning and productivity of aquatic ecosystems and the fish production systems they support.

Trade-offs and externalities can also happen between fish production and other aquatic ecosystem uses. Dam constructions, water abstraction, draining of wetlands are negatively impacting fish populations, with important implications for yields, protein supply and overall food security. Declines in migratory fish populations resulting from raw pollution discharge in rivers and lakes are also an illustration of the many instances where fisheries and/or aquaculture are bearing the brunt of development decisions that do not internalise the externalities they create. Although legal measures to limit and control the release of sewage effluents in the aquatic environment have allowed some fish populations to recover, drivers of change such as river damming, over-fishing, climate change etc. are often cumulative in their impacts, making the externality internalisation process difficult.

Addressing negative drivers of change on fisheries and aquaculture therefore means assessing and quantifying (i.e. costing) trade-offs occurring either within or outside the sector. Valuing the provisioning, regulating, supporting and cultural services supplied by inland capture fisheries and aquaculture systems, either independently or as part of the wider aquatic ecosystem, is an essential step in this process to ensure that the services of inland fisheries and freshwater aquaculture are recognised in production activities or in environmental management and protection measures. Valuation approaches applied to inland capture fisheries systems, in particular, have to account for the under-reporting of catches/yields from the sector.

Progressing towards a holistic assessment of the impacts, externalities, dependencies and trade-offs between fish production, water management and the benefits they generate

The main objective of the study is to develop a holistic assessment of different production and management scenarios in the inland capture fisheries and freshwater aquaculture sectors taking into account the (hidden) impacts, externalities and dependencies between fish production, environment and social and economic systems, and examining the full range of ecosystem services and trade-offs arising out of the use of aquatic ecosystems. The study takes stock of the current state of knowledge on the multiple services (benefits) that fish production generates, globally and in three case studies in North America (Columbia River), Asia (Lower Mekong Basin) and Africa (Lake Victoria). The case studies provide an analysis of the economic value of the provisioning, regulating, supporting and cultural services of inland capture fisheries and freshwater aquaculture under existing (baseline) and alternative water management scenarios. This allows quantifying the marginal changes in ecosystem services values arising out of management alternatives. The main ecosystem services considered in each system are: (i) food production (animal proteins and nutrients); (ii) water quality; (iii) biodiversity; (iv) carbon fixation and greenhouse gas emissions; (v) nutrient cycling; and (vi) income and livelihood support. Other ecosystems services are included if important.

Key findings from the case studies

The **Columbia River** (CR**), Lower Mekong Basin** (LMB) and **Lake Victoria Basin** (LVB) ecosystems support a wide array of ecosystem services. Fish production – through commercial capture, tribal, recreational and small-scale capture, as well as through aquaculture, is one of the most important provisioning service of these ecosystems. However, fish production is in competition with other water uses and management practices that seek to satisfy other development objectives and other needs. Key competitors are hydropower generation (CR and LMB) and use and transformation of wetlands (LVB) for agriculture and urbanisation. The case studies demonstrate significant trade-offs between fish production and the other uses of these aquatic ecosystems. Thus, externalities generated by other uses of wetlands, e.g. hydropower generation, and the unsustainable practices, are substantially affecting the benefits derived from the fish production service in all cases.

The total value of fish production is estimated at (2014): US$4.85 billion per year for the Mekong River Basin (riverine and reservoir capture fisheries and aquaculture), US$846.9 million per year for the Lake Victoria Basin (Nile perch and other main species fisheries and cage aquaculture), and US$107 million per year for the Columbia River (ocean and river commercial fishery, tribal fishery and recreational fishery (based on trip expenditures)) [5].

Scenario analysis suggests that, in the Lower Mekong Basin, if the construction of all mainstream dams proceeds as planned, it is estimated that the fish catch will decrease by 340 000 tonnes annually, suffering a loss valued at a more than US$476 million per year. This does not include the negative impacts this will have on the productivity of coastal and delta fisheries, which are also likely to be significant. Gains from newly created reservoir fisheries (but excluding aquaculture), though expected to be worth US$14 million per year, would far

[5] See notes in Table 3, Part 3.

from compensate the losses incurred. This is particularly important from a nutrition point of view as the amount of protein at risk of being lost annually represents 110 percent of the current total annual livestock production of Cambodia and Lao PDR.

Current management of the Columbia River includes many improvements for fish conservation. However, the scenario returning hydroelectric energy generation to past levels would result in a deficit in net social benefits of US$332 073 per year from cultural/subsistence fishing, US$961 861 million per year from commercial fishing and US$1.3 million per year from recreational fishing compared to the benefits obtained from these fisheries under the current management regime. Scenarios prioritizing water resources conservation over development can bring about many social benefits. In the Columbia River, where recreational fisheries is the most valuable ecosystem service, conservation would increase benefits to society by about US$3.3 million per year, compared to an annual loss of US$2.6 million if hydropower development was prioritised.

Wetland conservation also has an important regulating role in fisheries. For example, in Lake Victoria, the value of their regulating services can be substantial and comparable to the value of provisioning services (food). Thus, the planned conversion of wetlands to agriculture would require payments of 35 percent of the value of crops to farmers in the area to compensate for the natural nutrient buffering service formerly provided by the wetlands.

Fish production systems also support nutrient cycling. For example, anadromous salmonids swimming up to spawn after accumulating most of their adult body mass at sea, contribute to the cycling of nutrients from the ocean to areas far inland. In the Columbia River Hydropower, prioritization would result in a *net* loss of US$2 977 per year for the entire river compared to the current water management scenario. However, if the river were to return to pristine conditions, there would be a *net* social benefit of US$16 633 per year from nutrient imports by the salmon compared to current management scenario.

Fishers and fish farmers exploit aquatic ecosystems for fish, but are also in many ways the custodians of the fisheries and aquaculture systems in their care. Affecting one has repercussions on the other and vice-versa. Within the confines the three case studies, a profile of winners and losers from water management and development priorities emerges. In the Columbia River, losers from water development priorities are recreational fishers and the ecological and economic value of the recreational fishery in their custody. In the Lower Mekong and Lake Victoria Basins, losers are the local communities of small-scale fishers and non-fishing poor households whose part or entire livelihoods and wellbeing depend upon the health and good functioning of these aquatic ecosystems.

Transboundary services and externalities

The dependency of the services supplied by inland capture fisheries and freshwater aquaculture on the supply of a steady stream of good quality services from aquatic ecosystems is highlighted in all the case studies, echoing the interdependencies highlighted in Figure 1. Complexity is further increased by the transboundary nature of aquatic ecosystems and their resources (fisheries, water), which raises great challenges with regard to their management and may not be encountered to the same extent with other food production systems. The negative impacts of hydropower development in the upstream reaches of the Mekong River, for example, are felt all

along the course of the river, well beyond the national boundaries of the country immediately benefiting from hydropower generation. International treaties and commissions (e.g. Mekong River Commission) are not always adequately equipped to ensure that externalities on local livelihoods and ecosystems are internalised.

The transboundary nature of water and fisheries further confounds the distribution of benefits and costs of water management and fish production across societies and within social groups. The livelihoods and food security of poorer groups in the Lower Mekong and Lake Victoria basins depend on the direct and indirect benefits inland capture fisheries and freshwater aquaculture systems provide. This dependence is acknowledged in international instruments that recognize and support the rights of many fishing communities, including their right to adequate food. Examining trade-offs in the spread of benefits and costs across various social groups – not simply across ecosystem services – implies factoring in spatio-temporal distributional issues.

The distribution of inland capture fisheries and freshwater aquaculture benefits across customers groups is likely to vary widely, depending on their economic status (see above point about food security benefits of inland fisheries for poorer groups) and their location. Wealthier consumers in developed countries benefit from high-value fish production from more intensive systems (e.g. Lake Victoria's Nile perch commercial capture fishery and *Pangasius* produced in Vietnamese aquaculture ponds in the LMB) and their export to foreign markets (e.g. Europe, USA), whilst larger quantities of lower value species will be consumed domestically in developing countries. Intra-continental fish trade is however also extensive between neighbouring countries of sub-Saharan Africa and Southeast Asia and benefits consumers located in urban centres and at some distance of water bodies. Yet the precise extent to which one group may benefit or lose over another remains un-quantified.

Scaling up

Scaling up the findings of the case studies to a continental scale is extremely challenging. Underestimation is certainly the case for the fish production systems, owing to under-reporting of the catches and to gaps in the valuation approaches used. On a continental scale, the value of the regulating services of fish production systems and aquatic ecosystems appears most valuable, ahead of provisioning services, and that the value of cultural services is approximately of equal importance to that of supporting services.

Directions for future research

The current study identified many methodological challenges that remain to be addressed to ensure that trade-off analyses adequately capture the intricacy, complexity and multiplicity of the linkages that exist between all the system components. Economic valuation exercises need to embrace methods of engagement and become more participatory to better account for the differential in benefits accruing to winners and losers of ecosystem services. Without such engagement, it will be difficult to establish how different stakeholder groups (e.g. women, farms/households, local communities, consumers, and the global community) are affected by the trade-offs in ecosystem services.

The valuation of ecosystem services is an essential step in the recognition, capture and accounting of the benefits nature, water and fish production systems provide to societies. However, ecosystem services valuation and analysis of trade-offs should not be an end in itself. The process of appreciating the services yielded to humankind by ecosystems will be incomplete if two fundamental principles are not addressed: equity and resilience. Given the role fish plays in ecosystems, livelihoods, nutrition and economic development, the importance of distributional issues and the sensitivity to change of inland fisheries and aquaculture, these two dimensions of inland fisheries and aquaculture warrant further research.

The global analysis and the three case studies highlight challenges that could be addressed in follow-up studies:

- Setting the boundaries to the fish production systems under study. Although this is context specific, it is challenging when aquatic systems are transboundary and encompass multiple aquatic sub-ecosystems and fish production systems.

- Large variations in the quantity, quality and reliability of available data. Many data gaps remain to be filled and information requires harmonizing for valuation and trade-off analyses.

- How to better estimate values of ecosystem services and then assess more accurately different potential development/management scenarios. This could be filled with more research estimating:
    - The relationships between the effects of changes in management practices on ecosystem functions.
    - Their consequent variations in the value of these ecosystem services.

- How to better estimate and map global areas of wetlands and aquatic ecosystems and develop models to assess their productivity (e.g. Lymer et al. 2016a, 2016b). The spatial and temporal variations of aquatic ecosystem services flows and benefits, as well as the interdependencies between different ecosystem services, benefits and trade-offs would need to included.

- How can the quantitative impacts of the projected climate changes on freshwater aquatic habitats be determined, and externalities and their knock-on effects on the value of the ES supplied by inland fisheries and freshwater aquaculture be identified.

- How to include in cost-benefit analyses the distribution and consumption aspects of the broader food system and better encompass dimensions of food security, access, markets, agribusiness, supply chain, waste reduction throughout the entire value chain.

Policy recommendations

Planning, developing and managing freshwater aquatic ecosystems must include all ecosystem services and all sectors using the ecosystem. Fishers and fishery dependent communities are at risk of losing livelihoods from development of inland waters if such balance is not achieved.

Modelling of ecosystem services in a variety of ecosystems and sociocultural contexts is a useful method of assessing different water development and management scenarios, and should become standard practice for the formulation of policies concerning the maintenance and enhancement of inland fisheries and freshwater aquaculture's services.

International policies and laws support the rights of indigenous people, many of whom are fishers or rely on inland fisheries for livelihood and cultural identity[6]; these instruments need to adopted and implemented at more local levels. Development of water resources should respect their rights and ensure fair and equitable sharing of benefits from development of ecosystem services.

Overall, inland fisheries and freshwater aquaculture supply more services than 'disservices'. Continuous progress in the implementation of the Ecosystem Approach to Fisheries (EAF) and Ecosystem Approach to Aquaculture (EAA) in the context of freshwater capture and culture fish production is advancing the management of aquatic ecosystems towards the sustained supply of *all* their services. These efforts need to be pursued and strengthened at national levels and in transboundary water basins and should be given due recognition in high-level policy arenas (e.g. implementation of the Sustainable Development Goals). Key to this is the development of institutions capable of integration, in terms of shared objectives and standards.

Crucially, more commitment of will and finances is required to address the lack of basic data on inland capture fisheries catches and demonstrate the importance of the role and value of the sector in supporting livelihoods, nutrition and food security, economic development and wellbeing.

[6] See for example, the Convention on Biological Diversity; FAO. 2012. Voluntary guidelines on the responsible governance of tenure of land, fisheries and forests in the context of national food security. Food and Agriculture Organization of the United Nations, Rome. http://www.fao.org/docrep/016/i2801e/i2801e.pdf; FAO. 2014b. Voluntary Guidelines for Securing Sustainable Small-Scale Fisheries in the Context of Food Security and Poverty Eradication. Rome, Italy. http://www.fao.org/cofi/23885-09a60857a289b96d28c31433643996c84.pdf