# INLAND FISHERIES – PART 3

## [Exploratory Study – TEEBAgriFood]

# 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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## Preparation of this document

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- **Lower Mekong Basin** case study: Rattanawan (Tam) Mungkung, Ratcha Chaichana and Santi Senglertsawai, Kasetsart University, Thailand
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## Disclaimer



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# PART 3

# Discussion and Conclusions

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# PART 3: Discussion and Conclusions

# 5. DISCUSSION

## 5.1 Overview of the case study findings and ecosystem services dependencies

**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 hydropower generation and the unsustainable use of wetlands are substantially affecting the benefits derived from the fish production service in all cases.

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 likely to be significant, but have not been studied here. 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 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.

Although current management of the Columbia River includes many improvements for fish conservation, a prioritisation of 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 of the river. On the other hand, prioritisation of water resources conservation over development can bring about many social benefits. In the Columbia River still, 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 support a number of other services, although these are more rarely documented and valued. For example, anadromous salmonids swimming up the Columbia River to spawn after accumulating 95 percent of their adult body mass and a substantial amount of nutrients in their bodies while maturing at sea, contribute to the cycling of nutrients from the ocean to areas far inland. 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[1].

Beyond fish production, aquatic ecosystems have multiple other benefits, which are – and will continue to be – eroded by planned damming of the Mekong River and tributaries and the continuous alteration of wetland ecosystems around Lake Victoria. Changes in water quality and biodiversity have been quantified in bio-physical terms, but are more difficult to value in economic terms. Direct and indirect benefits in support of the livelihoods are however most important for those living within the catchments of the Mekong River and of Lake Victoria. In those areas, the generation of these benefits – in the form of nutrition, income generating activities, culture and heritage, knowledge etc. – are immediately connected to poverty alleviation and wellbeing, and yet most sensitive to ecosystem alterations.

The case studies also highlight the multiplicity of fish production systems, their context-specificity, and the range of benefits they provide to different social groups. Recreational fishing, so far mostly limited to developed, westernised countries, is a growing trend in developing countries. Its association with cultural services, and in particular tourism, can be used to capture the value of the cultural dimension of inland fisheries and aquaculture.

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[2]), US$846.9 million per year for the Lake Victoria Basin (Nile perch and other main species fisheries and cage aquaculture), and US$107 million per year for the Columbia River (ocean and river commercial fishery, tribal fishery and recreational fishery (based on trip expenditures)). Values obtained for the main ecosystem services considered in the Columbia River, Lower Mekong Basin and Lake Victoria Basin (i.e. (i) food production (animal proteins and nutrients); (ii) water quality; (iii) biodiversity; (iv) carbon fixation and greenhouse gas emissions; (v) nutrient cycling; and (vi) income and livelihood support) are summarised in Table 1, using a common unit of US$ per $km^2$ per year. Whilst this provides a sweeping overview of the wide variations in the ecosystem services encountered in the three aquatic ecosystems studied, it also highlights the gaps that remain in valuing many of the ecosystem services generated in the Columbia River, Lower Mekong and Lake Victoria Basins. The large differences in values among the case studies for a particular ecosystem service demonstrate the difficulties in comparisons among ecosystems.

For example, the three order of magnitude difference in the value of aquatic ecosystems for livelihoods between the lower Mekong Basin and Lake Victoria Basin is explained by a difference in what is included in each calculation as supporting livelihoods. Further studies allowing some standardisation across existing values and enabling better comparisons are needed.

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[1] These figures may seem small because they are net and account for the nutrients lost during spawning and rearing of juveniles. See Part 2, Tables 38 and 39.

[2] See note c in Table 3: Comprises Nile perch capture fishery, fisheries of other main species (from the case study) and all freshwater aquaculture (from FAO FishStat 2013) in Africa.

**Table 1:** Summary of the values of the key ecosystem services assessed in each case study (US$ per km2 per year in 2014)

| Ecosystem services | Values [range, where available] | Columbia River (US$/km2/yr) | Lower Mekong (US$/km2/yr) | Lake Victoria Basin (US$/km2/yr) |
|---|---|---|---|---|
| **Provisioning services** | Fish production | 187[a] | 24 541[b] [13-2 043 698] | 8 115[c] [2 066-3 924] |
| | Income and livelihood support | n/a | 3.6 [0.3-9][1] | 8 552[2] |
| | Food security | n/a | n/a | 43 786[3] |
| | Hydroelectric power generation | 945 487 | n/a | n/a |
| **Supporting services** | Water quality | 164 781 | 15 [8-25] | 838 706[4] |
| | Biodiversity | 696 | 1.21 [0.5-3] | 121 874[5] |
| | Nutrient cycling | n/a | 53 | 176 425[6] |
| **Regulating services** | Flood control | [2 675 257-17 492 066] | n/a | 2 009 955[7] |
| | Carbon fixation and GHG emissions | n/a | 24 [19-30] | 73 569[7] |
| **Cultural services** | Cultural heritage | [34-2 464] US$/household/year | n/a | 488 885[7] |
| | Recreation/aesthetics | n/a | n/a | 136 310[7] |
| | Research (fisheries) | 25 | n/a | n/a |
| | Tourism | 31 971 (fisheries) | 10 (wetlands) | 1 096 784[8] (wetlands) |

[a] Inclusive of commercial fisheries (ocean and in-river), tribal fisheries and recreational fisheries (ocean and in-river)'s total economic impacts.
[b] Includes riverine capture fisheries, reservoir capture fisheries ad aquaculture. The value of fish production from freshwater aquaculture systems comes from FAO FishStats Online (2013) for Cambodia, Lao PDR, Thailand and Viet Nam as it was deem more accurate than the figures presented in the case study.
[c] Includes Nile perch capture fishery, fisheries of other main species and freshwater aquaculture (adjusted figures from FAO FishStat 2013 for Kenya, Tanzania and Uganda to account for cage and other forms of culture).
[1] Based on values for Cambodia and Lao PDR (fish, aquatic animals, water birds, building materials), for Lao PDR (fish and aquatic animals for household subsistence) and Thailand (direct resource harvest).
[2] Based on values for Uganda (comprised of values of wetlands for cropping, livestock grazing, watering and milk production, excluding value for fisheries).
[3] Based on values for Uganda (value of wetlands for food availability and food accessibility, excluding value for fisheries).
[4] Based on values for Uganda.
[5] Based on values for Uganda (value of habitat/refugia as proxy).
[6] Based on values for Kenya.
[7] Based on values for Uganda.
[8] Based on values for Tanzania.

**Sources: case studies analyses (Part 2) and references therein, GDP deflators and population data from the World Bank**

As was suggested in Figure 1 in Part 1, 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. 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. These are particularly acute in the Lower Mekong Basin, in the Lake Victoria Basin and also, though to a lesser extent, in the Columbia River. 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. These costs, including those of livelihoods lost to displacement, inundated agricultural land and lost fishing, are not always adequately covered in hydropower development plans.

Although international treaties and commissions (e.g. Mekong River Commission) are in place to address conflicts and trade-offs, they are not always capable of ensuring that compensation for alterations in the functioning of ecosystems and decreases in their services are in place to mitigate negative externalities, including losses in the wellbeing of ecosystems and populations downstream.

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[3].

Examining trade-offs in the spread of benefits and costs across various social groups – not simply across ecosystem services – implies factoring in distributional issues. This is a highly complex task and would require several other scales and layers of analyses that were not possible in the present study. Beyond the destruction of ecosystems caused by the damming of watercourses, the generation of hydroelectric power also provides benefits across many social groups. Although not accounted for in the scenario analyses of the case studies, such benefits need to be born in mind.

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.

[3] For example Voluntary Guidelines for Securing Sustainable Small-Scale Fisheries in the Context of Food Security and Poverty Eradication (http://www.fao.org/fishery/topic/18240/en), the Voluntary Guidelines on the Responsible Governance of Tenure of Land, Fisheries and Forests in the Context of National Food Security (http://www.fao.org/docrep/016/i2801e/i2801e.pdf) and the recognition of the right to food under the Human Rights framework (De Schutter, O. 2014, Report of the Special Rapporteur on the right to food, UN Human Rights Council, http://www.srfood.org/images/stories/pdf/officialreports/20140310_finalreport_en.pdf).

Although not quantified, 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.

## 5.2 Scalability of the case study results to regional and global scales

The three case studies provide a regional, multi-country perspective on the use and value of inland capture fisheries and freshwater aquaculture under a range of development and water management scenarios. Scaling up and extrapolating their results to other aquatic ecosystems on the continents concerned is attempted here in order to provide an *order of magnitude* of the values. These estimates are subject to a number of assumptions and caveats. Upscaling to a global level would require additional data and information, and is not included here.

Lymer at al. (2016b) assessed the total global areas of different aquatic habitat that could sustain some type of inland capture fishery to be 10 404 450 km$^2$ (Table 2). Globally, it was assessed that there are 3 193 000 km$^2$ of lakes, 292 000 km$^2$ of reservoirs, 433 250 km$^2$ of rivers and streams, 3 215 000 km$^2$ of floodplains and freshwater marsh, and 3 271 200 km$^2$ of other types of wetlands. The distribution of different aquatic habitats per continent is presented in Table 2.

**Table 2:** Global wetland area (by habitat)

| | Habitat area (km$^2$) | | | | | Total area (km$^2$) |
|---|---|---|---|---|---|---|
| **Continent** | **Lakes** | **Reservoirs** | **Rivers and streams** | **Freshwater marsh, floodplain** | **Other wetlands** | |
| **North America** | 1 429 422 | 130 721 | 193 955 | 1 005 367 | 1 022 942 | 3 782 407 |
| **South America** | 127 144 | 11 627 | 17 252 | 559 161 | 568 935 | 1 284 119 |
| **Europe** | 224 387 | 20 520 | 30 446 | 91 206 | 92 800 | 459 359 |
| **Africa** | 302 235 | 27 639 | 41 010 | 460 939 | 468 997 | 1 300 821 |
| **Asia** | 1 092 572 | 99 916 | 148 248 | 1 001 859 | 1 019 372 | 3 361 969 |
| **Australia and Oceania** | 17 240 | 1 577 | 2 339 | 96 468 | 98 154 | 215 777 |
| **World** | 3 193 000 | 292 000 | 433 250 | 3 215 000 | 3 271 200 | 10 404 450 |

**Source:** Adapted from Lymer et al. 2016b

The theoretical average global potential production from inland waters, generated by multiplying adjusted yields with aquatic habitats areas, can be used as an estimate of the global natural capital of fish that is more accurate than officially-reported statistics (Lymer et al. 2016b). Thus, it is estimated at ~ 72 000 000 tonnes, with a 95 percent confidence range between 32 000 000 – 126 000 000 tonnes. Per continent, the theoretical average potential production is ~3 100 000 tonnes for North America, ~14 400 000 tonnes for South America, ~670 000 tonnes for Europe, ~5 000 000 tonnes for Africa, ~46 900 000 tonnes for Asia and ~ 2 000 000 tonnes for Australia and Oceania (Figure 1).

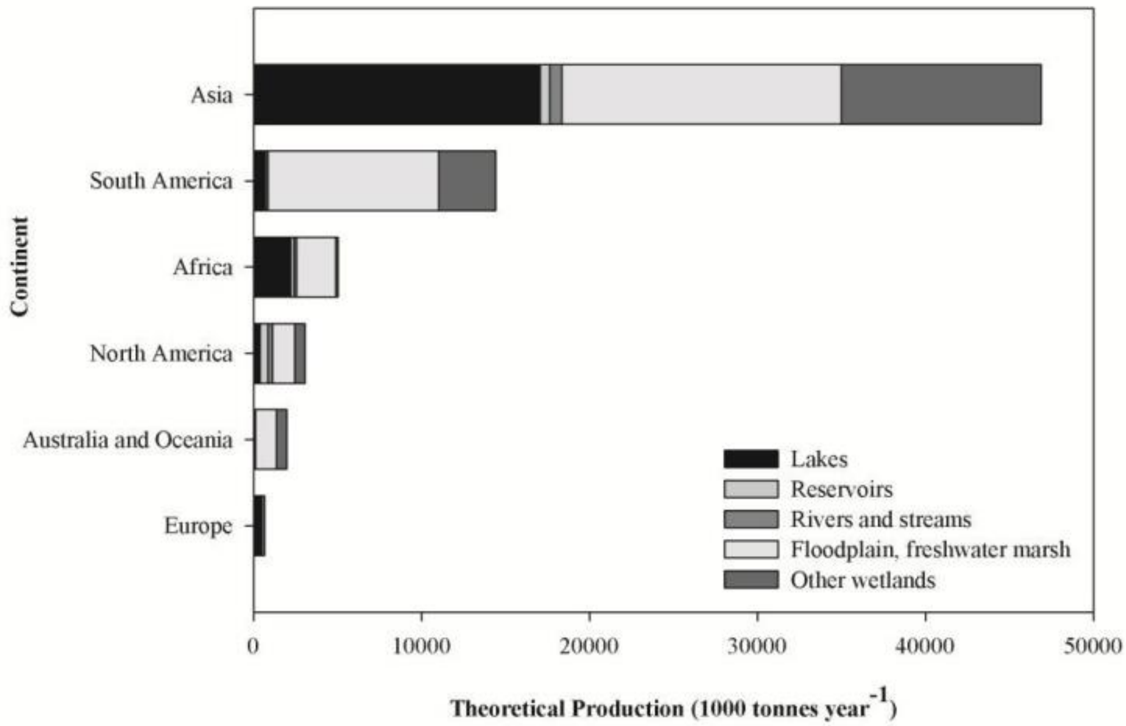


**Figure 1:** Estimated theoretical potential annual inland capture fisheries production (TPAP) per aquatic habitat per continent.
Source: Lymer et al. (2016b).

The global theoretical potential annual inland capture fisheries production is estimated to be on average 6.5 times higher than the official catch data submitted to FAO (between 3 to 11 times higher by continent) (Lymer et al. 2016b). Thus, the potential monetary and social value of inland capture fisheries and their contribution to food security and livelihoods is much higher than estimates based on the currently officially reported catches suggest. The large variations between reported yield from continents could have two likely causes: either the full production potential of inland waters is not fully utilized in certain continents (i.e. all waters are not managed for fisheries), or the production data are under-reporting achieved production of inland waters. In developed countries with other sources of protein and demonstrated decline in inland fishery production, it is more likely that the full production potential is not a priority and activities such as recreational fishing have become more important (FAO 2010). In developing countries, on the other hand, with inland fisheries playing a vital role in food security, it is likely that production is under-reported (Bartley et al. 2015).

The value of provisioning, supporting, regulating and cultural services valued in the case studies (Table 1) are scaled up to continent levels using information from the case studies, aquatic ecosystems areas

Table 3) and assuming that values for the ecosystem services of each case study are representative of those provided at the scale of the continent where they are located.

**Table 3:** Estimates of the value of ecosystem services from aquatic ecosystems of North America, Asia and Africa using case study results (US$ per year, 2014)

| | | | | | Values (US$) | Percent of total ecosystem services value |
|---|---|---|---|---|---|---|
| **Ecosystem service** | | **North America** | **Asia** | **Africa** | **Total across 3 continents** (in billion) | |
| **Provisioning services** | Fish production | 1.16 billion [a] | 82.5 billion [b] | 10.56 billion [c] | 94.22 | 0.18% |
| | Income and livelihood support | n/a | 12.1 million | 11.1 billion | 11.00 | 0.02% |
| | Food security[1] | n/a | n/a | 56.9 billion | 56.96 | 0.11% |
| | Hydroelectric power generation | 3 576.2 billion | n/a | n/a | 3 576.00 | 6.7% |
| | *sub-total* | | | | *3 739.00* | *7.01%* |
| **Supporting services** | Water quality | 623.3 billion | 50.4 million | 1 091 billion | 1,714.00 | 3.21% |
| | Biodiversity | 2.63 billion | 4.07 million | 158.5 billion | 161.17 | 0.3% |
| | Nutrient cycling | n/a | 178.2 million | 229.5 billion | 229.68 | 0.43% |
| | *sub-total* | | | | *2 105.00* | *3.95%* |
| **Regulating services** | Flood control | 10 119-66 162 billion | n/a | 6 757 billion | 44 898.00[d] | 84.16% |
| | Carbon fixation & GHG emissions | n/a | 80.7 million | 247.3 billion | 247.42 | 0.46% |
| | *sub-total* | | | | *45 145.00* | *84.63%* |
| **Cultural services** | Cultural heritage (fisheries) | 34-2 464 US$/ household/yr | n/a | 636 billion US$/km2/yr | 636.00[e] | 1.19% |
| | Recreation/ aesthetics | n/a | n/a | 177.3 billion (wetlands) | 177.00 | 0.26% |
| | Research (fisheries) | 94.5 million | n/a | n/a | 0.095 | 0.0002% |
| | Tourism | 120.9 billion (fisheries) | 33.6 million (wetlands) | 1,427 billion (wetlands) | 1 548.00 | 2.90% |
| | *sub-total* | | | | *2 361.00* | *4.43%* |
| | | | | | | |

| | | |
|---|---|---|
| ***TOTAL*** | *53 350.00* | *100%* |

[a] Comprises commercial fisheries (ocean and in-river), tribal fisheries and recreational fisheries (ocean and in-river)'s total economic impacts in North America (based on the case study), to which the value of freshwater aquaculture production in the USA and Canada (from FAO FishStat 2013) is added.
[b] Comprises riverine capture fisheries, reservoir capture fisheries and aquaculture (adjusted value of freshwater aquaculture from FAO FishStat 2013 for Cambodia, Lao PDR, Thailand and Viet Nam) in Asia;
[c] Comprises Nile perch capture fishery, fisheries of other main species (from the case study) and all freshwater aquaculture (from FAO FishStat 2013) in Africa.
[d] The median value of flood control in North America is used.
[e] The value of cultural heritage in North America is excluded.

The figures presented in
Table 3 are to be taken with extreme caution and a number of caveats need to be borne in mind. Figures provide an order of magnitude rather than absolute values. There are many reasons for this:

- The values for the ecosystem services of the Columbia River are assumed to be representative of those of aquatic ecosystems in North America, those of the Lower Mekong Basin of Asia, and those of Lake Victoria Basin of Africa.
- Further extrapolation to other continents on the basis of the data available from the case studies was not deemed reasonable.
- A number of ecosystem services are not included because values are not available.
- Many of the values used are context-specific (see Table 1 and case studies) and likely to be under-estimated.
- Some adjustments were made to the case study data to account for the discrepancies in aquaculture production and values between the case studies and FAO data (FishStat J), bearing in mind that FAO data is reported by country, not by watershed.

Underestimation is certainly the case for the fish production systems, due not only to under-reporting of the catches but also the fact that in the Lower Mekong and Lake Victoria values provided rely on the market value of the catch. They do not include other non-use values and do not encompass all the types of fish production systems encountered in these parts of the world (e.g. only riverine and reservoir fisheries and types of aquaculture for which data was available, e.g. cage culture in Lake Victoria, were considered in the case studies). However, by accounting for values of fish production systems and aquatic ecosystem services,
Table 3 suggests that regulating services are the most valuable, ahead of provisioning services, and that the value of cultural services is approximately of equal importance to that of supporting services.
Table 3 presents a value of US$94.22 billion per year for all fish produced from inland capture fisheries and freshwater aquaculture in North America, Asia and Africa. Whilst this may appear as a substantial amount, it only represents a meagre 0.18 percent of the value of all the other ecosystem services. It is most unlikely that such a percentage adequately reflects the importance of the multiple benefits of the sector, at multiple levels and to multiple stakeholders.

### 5.3 Lessons learnt and reflections on the process

The three case studies have shown that analysing fish production from an ecosystem services perspective is complex. Untangling the services supplied by fish production systems from those supplied by the aquatic ecosystem in which they are embedded proved difficult in most instances. The Columbia River case study was an exception in this regard and developed an innovative method to assess the values of several capture fisheries production systems, including their role in nutrient cycling, albeit pending access to good data availability and quality. The exercise confirms the paucity and patchiness of data and information to value the services from inland capture fisheries, and even more so freshwater aquaculture, pointing to new areas worthy of complementary research and work.

From a methodological point of view, the case studies highlight the power of using marginality analysis to demonstrate the impact of alternative development scenarios and uses in natural resources on ecosystem services values. Yet assessing the trade-offs this generates is no mean feat due to the intricacy, complexity and multiplicity of the linkages that exist between all the system components.

Trade-off analyses are highly complex as they imply:

I. Establishing a relationship between at least two of the variables, and
II. Testing the significance of this relationship.

In most cases this relationship is not linear, and if it is clearly established and characterised, it may not always be significant. For example, in two sub-basins of the Lake Victoria Basin, the linear relationship between agricultural production and sediment yield and loss of natural vegetation is not significant, highlighting that "there is no simple tradeoff between gains in agricultural production and losses of regulatory services" (Swallow et al. 1998: 30). In addition to occurring among multiple variables, trade-offs also occur at multiple scales, and affect a wide range of stakeholder groups, as was mentioned earlier. Their spatial and temporal dimensions are difficult to capture and require dynamic modeling. Multiple data sources are necessary, yet not always available or at the resolution required.

Economic valuation is a powerful tool, but all valuation methods have well-documented limitations. Participatory valuation is required to establish the differential perceptions of value by different stakeholder groups (Villamor et al. 2014). Without such engagement, it is more difficult to establish how different stakeholder groups (e.g. women, farms/households, local communities, consumers, and the global community) would be affected by the trade-offs resulting from different water management scenarios and development pathways. This is all the more challenging that:

I. there can be huge variations in the ways winners and losers experience trade-offs in ecosystem services and value their effects on the five main constituents of wellbeing (basic material needs; health; good social relations; security and freedom of choice and action – Suich 2012, cited in Upton et al. 2013),
II. wellbeing can be simultaneously derived from several ecosystem services,
III. cause and effect relationships between variations in ecosystem services and wellbeing are highly complex and variable, and often subject to the influence of un-related exogenous factors, such as institutions (Upton et al. 2013).

### 5.4 Challenges and areas for further research

Many challenges are in essence methodological. In summary, they relate to:

- understanding the functioning of ecosystems and identification of the services they supply,
- deploying appropriate valuation methods,
- designating beneficiaries and characterizing the flows of benefits across social groups,
- finding and accessing the relevant data to ensure capturing the differential in ecosystem values for different stakeholders,
- up-scaling ecosystem values across different ecosystems.

Addressing these barriers is essential for the recognition, capture and valuation of ecosystem services associated with inland capture fisheries and freshwater aquaculture, and aquatic ecosystems more generally, and should be the main endeavour of future work in this area.

### 5.4.1 Challenges associated with the study

Fish production and other ecosystem services have been documented to various extents in the selected case study areas, in comparison to the information available for other places. However, many information gaps remain because research findings on the supply and value of services from aquatic ecosystems and fish production systems are:

- Context-specific and ad-hoc (cf. Grantham and Rudd (2015)'s for a review).
- Limited to one or two ecosystem services per study, usually provisioning, regulating or supporting, paying little attention to cultural services.
- Focused on ecological processes, not always including economic valuation.
- Focused on larger aquatic ecosystems and the services they supply. Studies looking specifically at the services from the fish production systems – in particular aquaculture systems - embedded within these aquatic environments, are rare.

These limitations make extrapolation of ecosystem services values challenging. In addition, published trade-off analyses tend to focus on the production of agricultural, land-based commodities versus the maintenance of terrestrial ecosystem services, and usually do not consider effects on aquatic environments and fish production (e.g. Power 2010). The consideration of different stakeholders' perspectives and relative values of ecosystem services is also rare, and if encountered, not directly in the context of the aquatic ecosystems covered by the present study, which challenges the extrapolation of these studies to other areas (e.g. Upton et al. 2013).

Other challenges associated with the study, and in particular the case studies, revolve around:

- Setting the boundaries to the fish production systems under study. This was all the more difficult that all systems were transboundary and encompassed multiple aquatic sub-ecosystems and fish production systems. The choice of boundaries was in large part determined by information and data availability considerations.

- Large variations in the quantity, quality and reliability of available data across all case study areas.

- Difficulties in estimating variations in ecosystem services values under different potential development/management scenarios. This is because:

  - Relationships between the effects of changes in management practices on ecosystem functions are not always known or difficult to model/estimate with a reasonable degree of confidence.
  - Consequent variations in the value of these ecosystem services are even more difficult to establish.

- Limits to valuation also rest with other, ecological, data limitations. Advances in the fine tuning of estimates and mapping of global areas of wetlands and aquatic ecosystems and their productivity need to be pursued (e.g. Lymer et al. 2016a, 2016b).
- The identified externalities where not modeled or discussed in the context of climate change related projected changes to freshwater aquatic habitats. IPCC (2013) highlights that the observed and projected impacts of climate change on freshwater systems and their management are mainly due to increases in temperature and sea level, local changes of precipitation, and changes in the variability of those quantities. Semi-arid and arid areas are particularly exposed and there will be warmer water, more intense precipitation, and longer periods of low flow that will reduce water quality; with impacts on ecosystems, human health and food security, and reliability and operating costs of water services. Climate change affects water-management infrastructure and practice. Overall the negative impacts of climate change on freshwater systems outweigh its opportunities. The implications of climate variability and change on the contribution of freshwater fisheries to food security are expected to increase over time – both through direct and indirect climate change impacts as well as other drivers of change within the freshwater systems.
- This study focused on production values and did not reveal the economic value at distribution and consumption aspects.
- This study did not address the broader food system (e.g. include food security aspects, access, distribution, markets, agribusiness, supply chain, waste reduction etc.) but this should be considered in follow up studies.
- The values provided are “snap-shot” values and in a follow up phase it could be interesting to also consider how ecosystem services and the benefits they provide vary, both spatially and temporally.
- As there is comprehensive data available in each of the three case studies, analysis about the interdependencies between different ecosystem services, benefits and trade-offs could potentially be analyzed in follow up studies.

As a consequence, there is a limit to the extent to which valuation of ecosystem services is possible and to the number of ecosystem services for which a comparison of the impact of scenarios on their value is possible. As expected, cultural ecosystem services are the category of ecosystem services for which a comparative valuation under different development/management scenarios is the most complicated.

### 5.4.2 Avenues for further research

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, equity and resilience dimensions of inland fisheries and aquaculture warrant further research.

### *Equity - Sharing of ecosystem services (benefits)*

The linkages between ecosystem services and beneficiaries in the context of interlinked water-fish production systems are vitally important and merit closer examination and assessment, especially for international development agencies such as FAO whose main stakeholders are the rural poor. Frameworks such as the one developed by Fisher et al. (2014) (Figure 2) emphasize the link between ecosystem services and the factors allowing for the 'appropriation' of benefits, not just their generation and valuation. Such frameworks would be an interesting starting point in the examination of these linkages as they highlight the importance of looking beyond the generation of ecosystem services and consider which social groups reap their benefits. Questions such as who controls the distribution of ecosystem services (i.e. benefits) and how they are distributed among different stakeholder groups (e.g. the concentric circles of people in Figure 2) are fundamental to address in the context of water, fisheries and aquaculture as conflicts are rife in the appropriation of the services they provide. For example, whilst aquaculture development would benefit one sector of society, e.g. those with resources for feed, seed, land and water, another sector, e.g. small-scale fishers, might be deprived of access to water that is now used for aquaculture.

Similarly, numerous disputes are arising over 'rights to use', and in particular threats to indigenous rights by modified management and exploitation of aquatic resources, as was highlighted in Part 2 (Columbia River case study). More research needs to go into refining the framework proposed in Figure 2 to tailor it to the fisheries and aquaculture sectors to study the circumstances under which this happens (or not) would enable to better balance policy and development decisions. This is particularly important in the case of fisheries and aquaculture given the multiple and cross-linked dependencies between people, fish production and aquatic ecosystem health and sustainability.

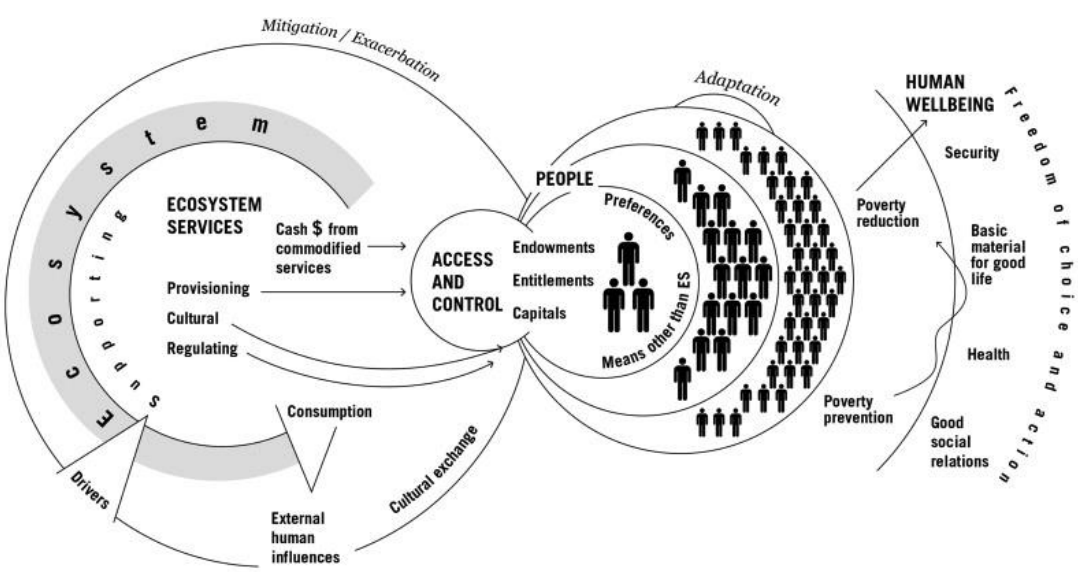


**Figure 2:** Fisher et al.'s (2014) conceptual framework linking ecosystem services and human wellbeing

### *Resilience*

A fundamental issue with ecosystem services, and those associated with fish production and aquatic ecosystems in particular, is how to determine where the limits and thresholds are in their delivery before these systems' functions are altered beyond irreversibility and the delivery of their services is modified to a point that the externalities generated require intervening. Moving the ecosystem debate into the realm of resilience and its associated concepts (Folke 2006) could enable considering not simply ecosystems' functions and values at a particular point in time, but rather identify a 'safe operating range' – akin to Rockstrom et al. (2009)'s 'planetary boundaries', either in biophysical or monetary terms, within which ecosystem services delivery can be altered over periods of time, but with acceptable consequences. Determining these thresholds ex-ante is a challenge that the scientific community must raise to in order to avoid the consequences of overtaking them. For example, entire fisheries have been completely closed following inconsiderate water management procedures and diversions in California (Obeji et al. 2008); fish and shrimp ponds have been demolished for undermining rice production in India and Thailand (Hambrey et al. 2008). Producing fish within safe ecological and social boundaries would ideally prevent the need for such drastic, ex-post, interventions to correct impacts and compensate for externalities.

# 6. CONCLUSIONS AND POLICY RECOMMENDATIONS

## 6.1 Concluding comments

Fish production from either capture or culture in the freshwater bodies of our case studies 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" (Aronson et al. 2010), i.e. as an investment in and replenishment of natural capital stocks to increase flows of goods and services from aquatic ecosystems.

However, 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 quantified.

The 'non-provisioning' ecosystem services are extremely valuable and often overlooked in development decisions. Trade-offs usually only consider the provisioning services that different ecosystem management scenarios involve. For example draining of 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 generated by water resources development such as hydropower and irrigation need to be more critically scrutinised 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. However, the commercial value of well-functioning aquatic ecosystems often goes unappreciated and neglected in developing water management objectives.

To a large extent, the maintenance and enhancement of the supply of freshwater fisheries and aquaculture services cannot happen without a simultaneous and urgent reform and reconsideration of the water use and management objectives of the aquatic ecosystems within which fish production is embedded.

## 6.2 Policy recommendations emerging from the study

Planning, developing and managing freshwater aquatic ecosystems must include all ecosystem services and all sectors using the ecosystem. "It makes no sense to develop one sector at the expense of another" (Árni Mathieson 2015 Europe's World). 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 in policy discussions.

International and national laws need to support the rights of indigenous people, many of whom are fishers or rely on inland fisheries for livelihood and cultural identity. Development of water resources should respect their rights and ensure fair and equitable sharing of benefits from development of ecosystem services (Lumley 2015).

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 ecosystem 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 (Soto et al. 2008).

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.

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