INLAND FISHERIES – PART 1

[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

Food and Agriculture Organization of the United Nations

The Economics of Ecosystems & Biodiversity

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PART 1

Context

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PART 1: CONTEXT

1. INTRODUCTION

1.1 General context, relevance and timeliness of the study

Ecosystem services are the benefits provided by ecosystems to humans. A widely accepted categorisation 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 (MA 2005). Nearly ten years ago, the Millennium Ecosystem Assessment, the largest scientific assessment of its kind, revealed that 60 per cent of the earth's ecosystems services were degraded or used unsustainably. Alarmingly, the use of two of these ecosystem services – capture fisheries and fresh water – was deemed "well beyond levels that can be sustained even at current demands, much less future ones" (MA 2005: 6).

There are two fundamental reasons as to why overuse and degradation of ecosystems and their services happens. The first is that most resource use and management decisions, influenced by policy distortions, imperfect information and high transaction costs, are based on the market value of services, e.g. fish sold as food, or units of water sold or consumed for drinking or irrigation. They do not account for the value of the other benefits provided. The second reason is that ecosystem services are interconnected and actions to increase one service are often at the expense of another, with unknown consequences for the future (MA 2005). For example, increases in food outputs - a provisioning service - through agricultural intensification have been matched by losses in supporting and other services such as biodiversity, nutrient regulation etc. (Foley et al. 2011, Zhang et al. 2007). Behind these choices are political and economic decision timeframes and motivations that rarely account for the long-term impacts of such trade-offs and impede the serious consideration of more sustainable alternatives.

In order to address this, and recognize the role of ecosystems as a feature of all societies, demonstrate their value in quantitative and qualitative terms, and capture this value in decision-making through price and policy signals, the "TEEB" initiative – The Economics of Ecosystems and Biodiversity – was launched in 2010. First a global study of the world's ecosystem services value, the initiative later commissioned more detailed biome and sector-specific studies and case-studies aimed at highlighting the economic importance and value of ecosystem services of water and wetlands (Russi et al. 2013), oceans and coasts (TEEB 2012, 2013, on-going) and, more recently, of agriculture and food production systems (TEEB 2015). Although fisheries and aquaculture are at the intersection of all these studies, the present study, aka "TEEB Fish", falls under the auspices of the latter (TEEB for Agriculture and Food, on the economics of eco-agri-food systems).

11.7 million tonnes of fish were landed from inland capture fisheries globally, representing only 13 percent of the total quantities landed in 2013[1] (FAO FishStat online query, 2015). However, this is believed to be an underestimate of the true landings (Bartley et al. 2015). Catches from inland waters have not increased significantly since the 1970s, although a significant portion of the catch goes unreported due to the informal nature of the activity. Yet, the actual contribution of inland capture fisheries to the livelihoods and food security of poor and rural communities in the developing world is massive (Bartley et al. 2015; World Bank et al. 2010). Conversely, the

[1] Excluding aquatic plants.

majority of farmed fish comes from inland waters (64 percent[2]), representing 56 percent 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 (Bostock et al. 2010). 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[3] have contributed to redress the development trajectory of both sectors. These however 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.

Inland capture fisheries and freshwater aquaculture are an integral part of the functioning and management of aquatic ecosystems. Considering fisheries and aquaculture through the combined lens of ecosystem services and TEEB is relevant and timely because it allows:

- Shining a light on the complexity of fisheries and aquaculture, which, unlike other sectors, are at the same time a productive system and a stock of natural capital, and untangling their relation with water and joint role in the supply of ecosystem services.
- Strengthening and bringing out the importance of economic valuation in the links that exist between fish production (either from capture or culture) and the supporting aquatic environment in which production takes place. This is important because it underpins decisions on the optimal allocation and use of resources to produce food whilst preserving the natural resource base, now and in the future.
- Shifting emphasis and supporting progress away from the traditional/neo-classical production perspective of fisheries and aquaculture management, to an ecosystem one in which relationships and dependencies between coupled social/economic and natural systems are examined and the wider range of tied ecosystem and human benefits and losses holistically embraced.
- Emphasizing the cross-sectoral nature of food production and ecosystem services.

This should also enable increasing the visibility of fisheries and aquaculture and their value in the water-energy-food 'nexus' discussions that are currently attracting attention and gaining momentum in the research and development arenas.

1.2 Scope of the study

This study is enshrined in the 'sustainable development' paradigm proposed by ecological economists on the need to revert economic development under the prevailing "business as usual"/neoclassical economic scenario (e.g. Boulding 1966, Daly 2003), and is focused on the application of this paradigm to food and agriculture. More specifically, the study is framed by the principles of the ecosystem approach to fisheries and aquaculture, EAF and EAA, which in

[2] Excluding aquatic plants.
[3] Ecosystem Approach to Fisheries (EAF) and Ecosystem Approach to Aquaculture (EAA); see FAO 2003, FAO 2010a.

essence, support a holistic consideration of the development of both sectors and their interactions with others (FAO 2003, FAO 2010a). This report retains the classification of ecosystem services of the Millennium Ecosystem Assessment (2005) as provisioning, supporting, regulating and cultural.

In line with the great threats that freshwater resources are facing (MA 2005), this study focuses strictly on **inland capture fisheries**[4] and **freshwater aquaculture**[5] production systems, regardless of their form, scale and intensity. It encompasses all freshwater aquatic environments, whether they are man-made (e.g. reservoirs) or natural (e.g. rivers). As a consequence, it excludes all coastal and marine fish production, whether from capture or culture and excludes brackish, coastal and marine aquatic ecosystems[6].

The paper notes that monetary valuation has many limitations, e.g. subjective, anthropocentric, context-specific etc. (Ekins 2011). However, in the absence of better proxies to demonstrate importance and economic worth, it remains one of the best ways to encourage the accounting of externalities and trade-offs in decision-making (Russi et al. 2013).

Here we conceptualise fish as both a living stock of natural capital and as a product of aquatic ecosystems. However, given the fundamental linkage of fisheries and aquaculture with water, water use and management issues are an integral part of this study. Furthermore, as will be demonstrated later in the case studies (Part 2), fisheries and aquaculture are part of complex social-ecological systems where flows, feedback loops and interactions between multiple variables, challenge the analysis of impacts and trade-offs resulting from changes pressed upon them.

1.3 Objectives

This study is one of the "feeder studies" contributing to the TEEB for Agriculture and Food initiative. The main objective of the present 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.

This involves three steps:

1. A data gathering and stock-taking exercise, analysing the positive and negative impacts and externalities of inland capture fisheries and freshwater aquaculture production systems across the world (this volume).
2. An integrated assessment and valuation of ecosystem services associated with fish production in three case study areas: Columbia River, North America; and Lower Mekong Basin, Southeast Asia; Lake Victoria, East Africa (Part 2).

[4] See chapter 3 for definitions and further information on inland capture fisheries
[5] See chapter 3 for definitions and further information on freshwater aquaculture
[6] It should be noted however, that rivers and other inland aquatic ecosystems do provide economic benefits to marine and coastal areas in the form of nutrients (regulatory), sediments (supporting), freshwater (supporting and regulatory) and migratory pathways for fish (provisioning).

3. A synthesizing exercise pointing towards policy options and recommendations to improve the sustainability of fish production practices and aquatic ecosystem management on the basis of previous two steps (Part 3).

To set the scene, this document starts with a conceptual discussion on the place of fisheries and aquaculture in the ecosystem services discourse (section 2). An overview of the positive and negative impacts and externalities of inland capture fisheries and freshwater aquaculture production systems, as well as the trade-offs resulting from alterations in the ecosystem services they both rely on and supply, is then provided (Section 3). In Part 2, Section 4 outlines the valuation of ecosystem services in three aquatic ecosystems and fish production case studies. In Part 3, Section 5 synthesises and discusses the case study findings, also elaborating on challenges and areas for future research. Study highlights and policy recommendations are provided in Section 6.

2. PLACING FISHERIES AND AQUACULTURE IN AN ECOSYSTEM SERVICES PERSPECTIVE

This section describes the relationship between the concepts of externalities and trade-offs in relation to fish production and water management. It highlights that considering fisheries and aquaculture from an ecosystem services perspective is extremely complex and strives to shed light on the challenges associated with this complexity.

2.1 Trade-offs and externalities

Trade-offs and externalities result from management choices that change the type, magnitude, and/or the relative mix of services provided by ecosystems (MA 2005). A negative externality is said to exist when damage caused by a party on another remains uncompensated (Pearce and Turner 1990). This happens when the cost of the damage that led to the loss of human welfare and/or ecosystem integrity is not internalised in the production process. An externality can also be positive when it translates into a benefit experienced by third parties. As such, positive externalities are often associated with the production of public goods (Hanley et al. 1998). Trade-offs are the decisional compromises arising out of choices made between a range of alternatives and resulting in opportunity costs.

Trade-offs are anchored in Pareto optimality: resolving a resource allocation issue involves finding a set of solutions in which it is impossible to make any one individual better off without making at least one individual worse off. Winners and losers can be individuals, groups or entire sectors. Internalising the cost of the consequences of the trade-off made on other users (i.e. the negative externality) would, in theory, enable one to proceed with their preferred choice. In practice however this rarely happens as it relies on the accurate valuation of the multiple – marketed and non-marketed – services supplied by the resource at stake, and on sound institutions in place for compensation to happen. Another reason for which this does not happen is because overcoming trade-offs can imply *more* than just solving an economic problem of "constrained optimisation"[7]. Resolving trade-offs also implies giving due consideration to some particular sustainability issues such as substitution of natural capital for other forms of capital[8] and discounting, and to some behavioural and ethical dimensions such as human choices and rights of future generations – all of which are not necessarily captured in straight-forward economic optimization.

Whilst trade-offs underlie all discussions on the use of natural resources and the pursuit of sustainable development, balancing and accounting for the negative and positive externalities they generate is not straightforward for three main reasons:

1. In the context of ecosystem services, trade-offs are often multi-dimensional, i.e. between more than two categories of services. Although efficiency frontier approaches (i.e. the building of a trade-off curve) have been used to model trade-offs between two ecosystem services (e.g. Carden et al. 2013), they tend to oversimplify reality and risk, undermining decisions despite their strong visual and communication power (Hurford et al. 2014). In

[7] "Constrained because of the scarcity of resources at our disposal; and optimization because we wish to extract the greatest possible net benefit from them" (Bateman et al. 2014: 14).

[8] Substitution of natural capital for another form of capital is called weak sustainability. Strong sustainability on the other hand recognizes that substitution of natural capital is seriously limited by irreversibility, uncertainty and the existence of critical components of natural capital, which make its contribution to human welfare unique (Pearce et al. 1990).

addition, the feedback loops that tend to exist between and within the supply of services from various categories of ecosystem services make their assessment all the more challenging.

2. Given the dynamic nature of ecosystem services, trade-offs are not fixed in space and time: they have spatial and temporal dimensions, and a degree of (ir)reversibility (MA 2005, Rodriguez et al. 2006). This implies that ecosystem services delivered within short time frames – typically provisioning services – are usually preferred as they satisfy immediate human needs and are more easily economically quantified than regulating, cultural and supporting services (Foley et al. 2005, Rodriguez et al. 2006). This gives rise to the additional challenge of locating where, and discerning upon whom, the gains and losses resulting from the trade-off decisions will fall (Bateman et al. 2014). Many of the externalities generated by uses of natural resources fall across society at large and remain unaccounted for. Identifying "the precise distribution of benefits and costs within and across society" (ibid, p. 11) is therefore an integral part of the assessment and solving of trade-offs.

3. Trade-offs often involve choosing among decision outcomes expressed in multiple units that are difficult to compare and to which a wide range of values are likely to be attached. Assigning monetary values to different outcomes, although not always straightforward either, nonetheless enables imposing some 'common currency' or commensurability across multiple units and assisting with the identification of those options that deliver the greatest net benefits to society" (Bateman et al. 2014: 12).

2.2 Water, fish and fisheries in aquatic ecosystems

The MA (2005) chose a simple and easily communicable definition of the benefits people draw from nature, whether directly or indirectly, by calling them "*services*". This simplification is however somewhat problematic for economists who traditionally prefer to distinguish benefits as either 'functions', i.e. the biogeochemical processes and life-support role that ecosystems components enable (e.g. waste recycling), or as 'products', i.e. the goods produced by that same ecosystem (e.g. plants, animals, minerals) (Daily 1997).

Whereas ecosystem products are generally tradable and their value is determined on markets, the value of ecosystem services isn't captured in price signals, which makes their valuation much more difficult. Ecosystems' functions become a service (i.e. benefit) when humans place a value on them, or when the function fulfilled by ecosystems is damaged and translates into a tangible loss in human welfare (Ekins 2011[9]). This is not just semantics: distinguishing the services of aquatic ecosystems, including fisheries and aquaculture, from the products stemming from their exploitation, helps to better recognise the role and value of each.

Water is a stock of natural capital that provides a flow of services and life-supporting functions without which we would not survive. Without human intervention, the function of aquatic environments is to support and regulate other natural (biogeochemical) phenomena occurring naturally on Earth, as well as fulfil a cultural and social role for the societies who either live in

[9] Hence the distinction that Ekins (2011) makes between functions *of* ecosystems and functions *for* humans, i.e. services. A similar notion is that of intermediary services and final services provided by nature (UK NEA 2011). Note however that the distinction between functions and services is not always clear in the literature.

the vicinity of these environments, or depend upon them for their livelihoods, economies and wellbeing.

The supply of freshwater is a provisioning service from freshwater aquatic ecosystems. In other words, water is a product of freshwater aquatic ecosystems. However, because freshwater supports life and is also an input into anthropogenic production processes and activities (e.g. fishing, fish farming, agriculture, manufacturing, energy generation), it is also a supporting service (MA 2005). Table 1 highlights the multiple roles of aquatic ecosystems. Extracting water from rivers and lakes for drinking, sanitation, irrigation and industry can conflict with the maintenance of stream flow or lake levels that are required for other services, such as power generation, fish production, transport, waste removal, and recreation (Rodríguez et al. 2006).

Wild fisheries stocks are a form of natural capital from which services flow over time (after the definition of 'natural capital' by Costanza and Daly 1992). For some of these services to become benefits (e.g. fish as food), some human intervention is required (e.g. fishing effort, fishing knowledge, fishing communities) to build, maintain or harvest this stock of natural capital (i.e. the fishery) (Costanza et al. 2011). However, other benefits can flow without human intervention: fisheries do 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 (Holmlund and Hammer 1999).

Aquaculture systems can be considered in a similar way. 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 also occur simultaneously without human intervention, as will be described in Section 3.

Table 1: The functions, services and products of aquatic ecosystems and their correspondence with the MA's classification of ecosystem services

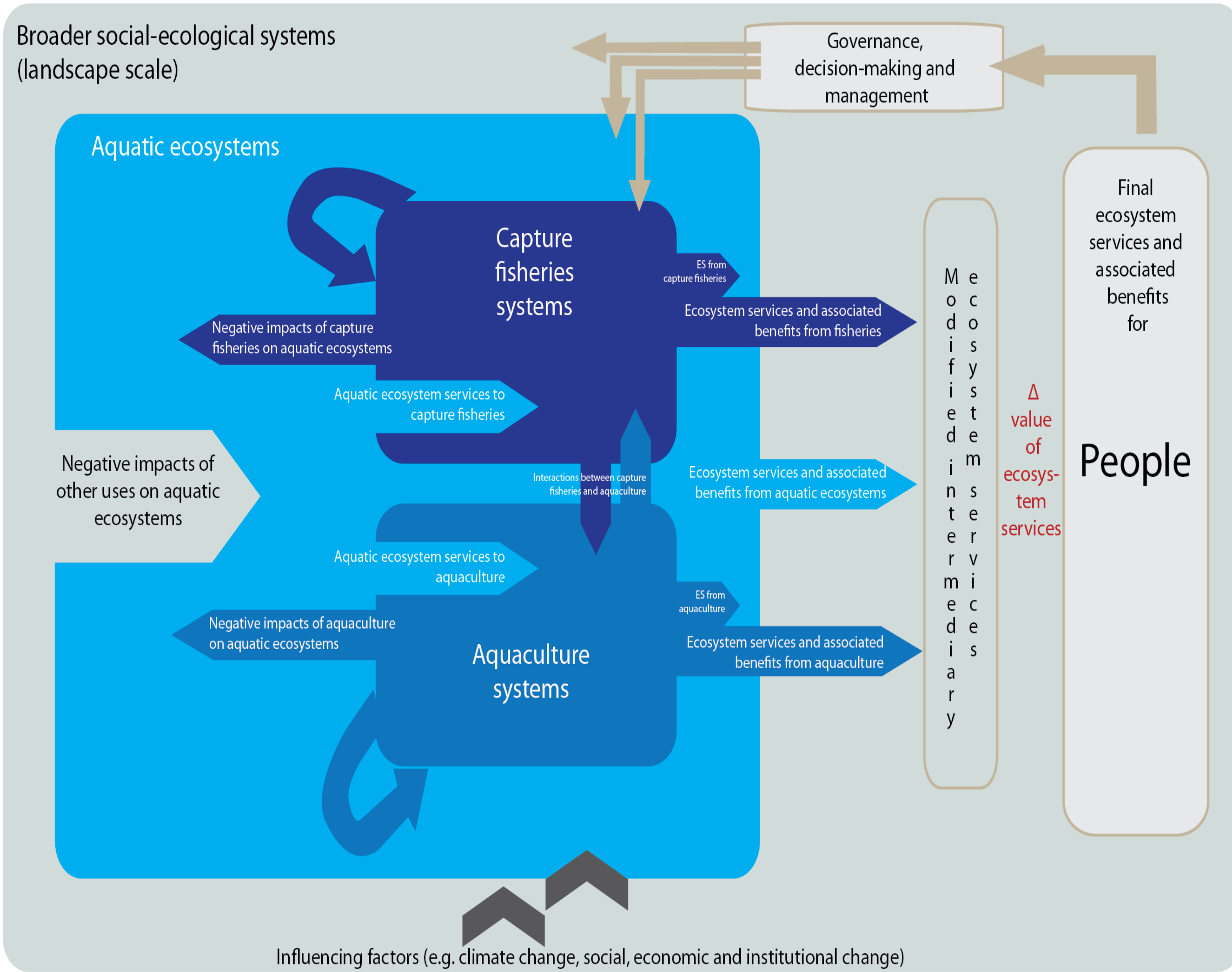
	Outcomes																												
	Goods					Goods AND Services			Services																				
Functions	Potable water for household use	Water for crop irrigation	Water for livestock consumption	Water for food processing	Water for other manufacturing processes	Fish and other aquatic products	Cooling water for power plants	Energy generation	Water-based transport	medium for wastes and other by-products of human	Water for landscape maintenance and peat soil	the support of living organisms	Biological diversity support	prevention of land subsidence	Prevention of saline intrusion	Natural erosion, storm and flood protection	Shoreline stabilisation	Sediment removal	Micro-climate regulation	Macro-climate regulation	Toxin removal	Toxin export	Fishing, hunting, trapping and plant gathering[1]	Recreational swimming, boating, and other water-based leisure activities	and study for leisure, education and scientific	Cultural value	Historical value	Aesthetic value	Wilderness value
Water discharge	*	*	*	*	*		*	*	*	*	*	*	*						*	*		*		*	*	*			
Water recharge	*	*	*	*	*		*	*			*	*	*	*	*				*	*				*	*				
Flood mitigation/ control	*							*					*	*		*									*				
Sediment retention	*					*			*			*	*	*		*	*	*			*		*	*	*			*	
Nutrient retention						*		*		*	*	*	*										*	*	*				
Nutrient export										*		*	*											*	*				
Trace element storage						*							*								*		*	*	*				
Trace element export													*									*			*				
Carbon sequestration								*			*		*							*				*	*				
Biodiversity maintenance						*					*	*	*						*				*	*	*			*	*
Culture/heritag e						*																	*	*	*	*	*	*	*
MA classification	PROVISIONING					PROV. & SUP.	SUPPORTING								REGULATING									CULTURAL					

The relation between fish production and freshwater aquatic ecosystems is summarised graphically in the conceptual framework presented in **Error! Reference source not found.**. his 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. It should also be noted in this context that 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).

Narrative for Figure 1: Inland capture fisheries and freshwater aquaculture systems are embedded in aquatic ecosystems, which are themselves stocks of natural capital. These are subjected to other uses (e.g. irrigation), as well as exogenous influences (e.g. climate change), which may compete with and alter the state and delivery of the aquatic ecosystem services necessary for capture and aquaculture fish production systems. Both capture fisheries and aquaculture systems also operate as a form of stock of natural capital, or "ecosystems" – supplying services to the aquatic environment they are embedded in, as well as to the wider social-ecological system they are also a part of. Improperly managed and developed, capture fisheries and aquaculture systems can however also cause negative impacts that affect the ability of both aquatic ecosystems and fish production systems themselves to sustain their functioning and services (the rounded feedback arrows).

Important ecosystem services interactions also exist between capture fisheries and aquaculture (e.g. effect of introduced species for aquaculture on local endemic fish species, or support role of hatchery-raised fingerlings for the enhancement of capture fisheries stocks – "culture-based fisheries"). Ecosystem services resulting from the functioning of aquatic ecosystems, capture fisheries and aquaculture systems are delivered to the wider social-ecological system in the form of intermediary services (e.g. food production, water quality, biodiversity, carbon fixation, nutrient cycling, cultural heritage). Changes in the supply of these services translate in variations (Δ) in the way people directly experience them and benefit from them (e.g. food, nutrition and income security, good health, cultural identity and spirituality etc.). Variations in the quality of these experiences, either positive or negative, can be quantified and valued, allowing insights into the resulting losses or gains in human welfare ("externalities").

The recognition and capture of these values and corresponding negative and positive externalities in the institutional structures and processes that govern and mediate decisions on environmental management and food production and the distribution of their benefits, creates leverage for the improved management of aquatic ecosystems and the fish production systems they host.



Broader social-ecological systems (landscape scale)
Governance, decision-making and management
Aquatic ecosystems
Capture fisheries systems
ES from capture fisheries
Ecosystem services and associated benefits from fisheries
Negative impacts of capture fisheries on aquatic ecosystems
Aquatic ecosystem services to capture fisheries
Negative impacts of other uses on aquatic ecosystems
Interactions between capture fisheries and aquaculture
Ecosystem services and associated benefits from aquatic ecosystems
Aquatic ecosystem services to aquaculture
ES from aquaculture
Negative impacts of aquaculture on aquatic ecosystems
Ecosystem services and associated benefits from aquaculture
Aquaculture systems
Modified intermediary ecosystem services
Δ value of ecosys-tem services
Final ecosystem services and associated benefits for
People
Influencing factors (e.g. climate change, social, economic and institutional change)

2.3 Capturing the value of coupled water-fish production systems

Fish production is totally dependent upon the availability, quality and primary production of another stock of natural capital: water. Aquatic ecosystems are therefore our starting point, not the fish production system per se. As was highlighted in **Error! Reference source not found.**, e consider aquatic ecosystems as a stock of natural capital within which the production of fish from inland capture fisheries and freshwater aquaculture is nested. Thus, capture fisheries and aquaculture are a way to harness some of the benefits of aquatic ecosystems, whilst being themselves a source of benefits. Consequently, our approach goes beyond what would be akin to a 'cost-benefit analysis' of fish production systems. In line with TEEB, our approach to valuation is enshrined in the concept of marginality as a general conceptual framework for the economic valuation of ecosystem services.

Marginality represents the *change* in ecosystem service supply that can be experienced, and therefore valued, by people in a particular context (TEEB 2009). If total economic value (TEV) is sometimes promoted as a framework that demonstrates the multiple types of values that ecosystems have, such a framework is limited in its application because valuing some of the ecosystem functions will always result in an underestimation. In addition, such information is not always relevant for policy makers: showing a real or potential change in an ecosystem service delivery due to a particular use or policy can be more meaningful for stimulating corrective action than knowing its value in absolute terms. The use of marginality in ecosystem services valuation was for example operationalized in the assessment of the United Kingdom's ecosystems (UK NEA 2011). It is represented in Figure 1.

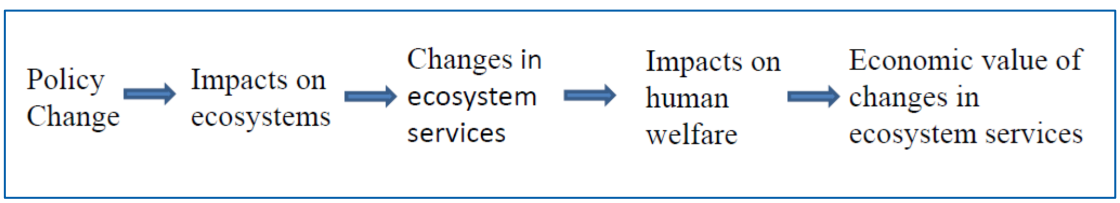


Figure 1: ***Assessing ecosystem services' values through marginality (changes). Source: TEEB 2009***

3. PRODUCTION, POSITIVE AND NEGATIVE EXTERNALITIES OF INLAND FISHERIES AND AQUACULTURE PRODUCTION SYSTEMS: A GLOBAL OVERVIEW

3.1 Overview and impacts of major fish production systems

Inland capture fisheries

Inland capture fishing takes place mainly in rivers, lakes, reservoirs, other wetlands[10] and coastal transitional, brackish habitats which cover an area estimated to range between 4 and 7.8 million km^2 (Welcomme et al. 2010, de Graaf et al. 2015). Freshwater fishes comprise nearly 13 000 species (and 2 513 genera) (including only freshwater and strictly peripheral species), or about 15 000 if all species occurring from fresh to brackish waters are included (Levêque et al. 2008). Out of these, only 257 species are reported as caught by capture fisheries (FAO Fishstat 2014).

A large fraction is reported as freshwater fishes *nei (not elsewhere included)* or [family] *nei*. Of the total reported production[11] (11.6 million tonnes in 2012, of which the bulk is freshwater fish - Figure 2), 22 percent are reported at species level and almost 60 percent are reported as Freshwater fishes *nei* (Table 2). Thus, the 257 reported species are most likely an underestimation of the biodiversity harvested from inland waters by capture fisheries. Generally, fish biodiversity is greater in the tropics than in temperate inland waters (Amarasinghe and Welcomme 2002).

The ecology of the fish populations in lakes, rivers, reservoirs and other types of wetlands is very different (Welcomme 2001). Although the precise state of many inland fisheries stocks is not known, in many instances the quality of the aquatic environment is a stronger determinant of the state of the stock than fishing pressure itself. Variations in flows caused for example by damming and flooding, or eutrophication, are major environmental drivers affecting the state and productivity of a fishery (Welcomme et al. 2010, Welcomme et al. 2014).

However, multi-species, multi-gear fish assemblages and fisheries in inland waters also respond to drivers such as heavy fishing or use of illegal methods according to a model known as the fishing-down process (Welcomme 1999). This predicts that, with increases in fishing pressure (effort), the larger individuals and species will be successively reduced and even lost from the fishery (overfishing of species) until only the smaller species remain to form the basis for the fishery. As a consequence, one of the symptoms of intense fishing in inland waters is the collapse of particular stocks even if overall fish production rises, giving rise to a biodiversity crisis rather than a fisheries crisis (Allan et al. 2005). Because smaller species are generally more biologically productive, and many of the larger species are fish-eating predators, production of the fish assemblage as a whole tends to be very resilient, so the level of catch can remain the same over a considerable range of fishing pressures (Welcomme et al. 2010).

[10] The term "wetlands" is used in different contexts to mean different things. It can mean everything that is wet (as per the Ramsar definition, UNESCO 1994), which in this case also includes lakes, rivers and reservoirs. It can also be used in a limnology (Wetzel 2001) sense where wetlands are all wet lands that are not lakes, reservoirs, ponds and river and stream channels (e.g. swamps, marches and floodplains).

[11] The reported figures to FAO are not divided by freshwater habitat (e.g. lake or river) or by economic sector (e.g. subsistence, commercial or recreational).

Table 2: Level of detail in reporting and major reported species and "nei" groups from global inland capture fisheries 2012 (Source: FishStats J)

Species/family/group	Production (tonnes)
Nile perch	278 675
Silver cyprinid	241 122
Nile tilapia	235 003
Hilsa shad	120 167
Common carp	85 197
[Engraulicypris sardella]	84 082
Striped snakehead	76 793
Dagaas	63 381
Chum(=Keta=Dog) salmon	63 009
Silver barb	55 612
Others at species level	1 046 960
Subtotal species level reported	*2 350 001*
percent of total	*22%*
Freshwater fishes nei	6 327 387
Cyprinids nei	838 616
Tilapias nei	388 236
Freshwater siluroids nei	197 730
Torpedo-shaped catfishes nei	106 136
Other "nei"	471 364
Subtotal "nei"	*8 329 469*
percent of total	*78%*

Owing to their nature, inland fisheries catches are widely under-reported (Bartley et al. 2015), although they are estimated to be rising at a linear rate of about 3 per cent per year globally (Welcomme et al. 2010 and Figure 2). Main producing continents are Asia and Africa with almost 92 percent of the production. The reason for under-reporting differs between industrialized and developing countries. In industrialized countries, recreational fisheries are seldom reported in official statistics (Welcomme 2011, Cooke and Cowx 2004), which tends to focus on commercial landings. In developing countries, the widespread nature and high level of subsistence fishing tend to confound official figures (Welcomme 2011). Current available data are therefore sufficient only for a general overview of global inland fish catches, rather than for the detailed analysis needed for the management, policy formulation and valuation of inland fisheries (Welcomme 2011).

Inland capture fisheries are currently undergoing two major trends. The first trend is one of enhancement, through the implementation of stocking programmes to increase the productivity of lakes and floodplains and to mitigate for loss of spawning habitat (e.g. salmon stocking programmes in North America), and through traditional stocking practices of seasonally wet environments such as rice fields, as is widely practiced in China and other parts of Asia (Bartley et al. 2015, Halwart and Gupta 2004).

The other trend is a shift towards recreational fishing activities which are increasingly popular and becoming a major use of aquatic ecosystems, in particular in industrialized countries (Arlinghaus et al. 2015). These trends are not meant to take away from the extremely productive capture fisheries that are not stocked or practiced in rice fields, e.g. the Mekong River.

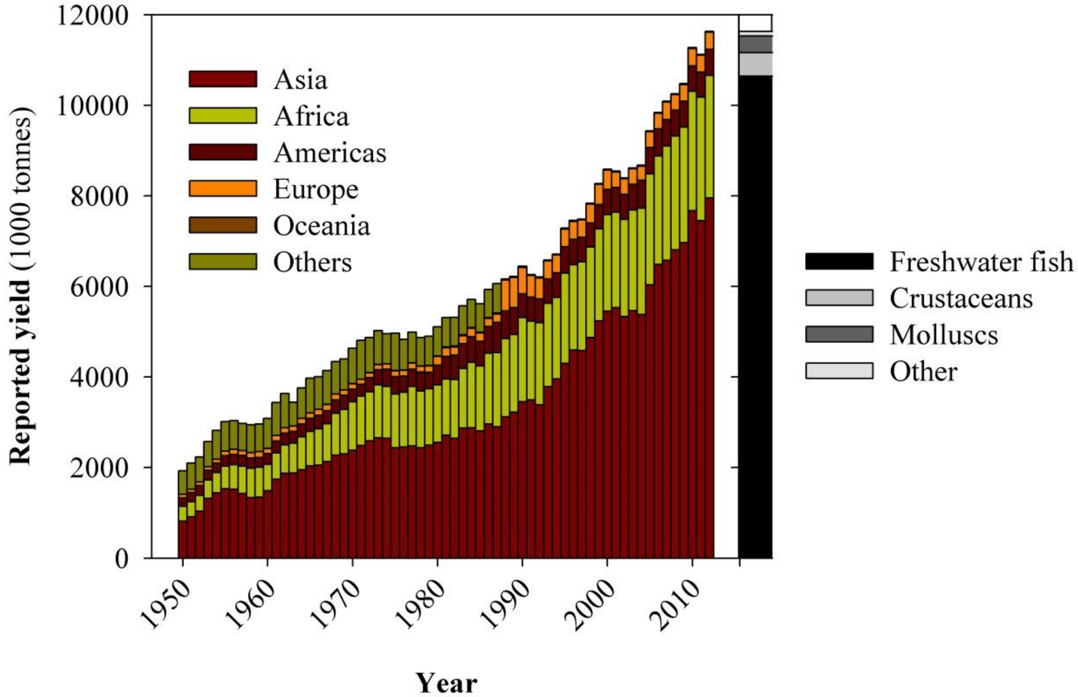


Figure 2: Production from inland capture fisheries 1950-2012 by continent and by main groups, where other includes marine fish, aquatic plants and aquatic animals
(Source: FishStat J 2015).

The bulk of inland capture fisheries' catches, global value, and use for domestic consumption come from small-scale operations (Welcomme et al. 2010, World Bank et al. 2010). 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 (World Bank et al. 2010). Fishing is generally carried out as a mainstay or supplementary livelihood activity in which men and women equally participate (FAO 2010). By-catch is insignificant as most of the fish caught is consumed locally, providing an important source of protein and crucial nutrients (Roos 2015, Thilsted 2015) in often poor and remote communities (Welcomme et al. 2010, Welcomme et al. 2014).

Recreational fisheries, with a global participation of between 118 (Arlinghaus et al 2015) and 700 million people (Cooke and Cowx 2004), is the dominant or sole use of most wild-living freshwater fish populations in all industrialized countries. Several economies in transition (e.g. Brazil) are also predicted to increase recreational fishing (Arlinghaus et al 2015).

In addition to, and as a consequence of, the under-reporting of inland capture fisheries, market value estimates reflect only the direct use value of these fisheries and therefore under-estimate the full value of these fisheries and their importance of their role in the economy, livelihoods and maintenance of ecosystems. Consumer and producer surpluses have been estimated for a number of individual commercial, recreational and subsistence/ artisanal fisheries. However, these studies are often carried out on an ad-hoc basis, which constrains extrapolation to other fisheries and results in the overall under-estimation of the value of the multitude of services that these fisheries supply (Grantham and Rudd 2015).

Although inland capture fisheries are usually suffering from environmental alterations arising from outside the sector, producing fish through inland capture fisheries can also generate negative impacts. In the case of small-scale, artisanal, fisheries, this has been shown to happen when non-selective or illegal fishing gear (e.g. mosquito nets) is used and fishers do not comply with fisheries management measures (Kibria and Ahmed 2005 on the overfishing of Bangladesh's floodplains). Recreational fishing can also negatively impact on wild fish species fitness, survival and assemblage (Sutter et al. 2012). Species introductions in support of industrial fisheries have also had unpredictable impacts on local aquatic fauna (e.g. Nile perch in Lake Victoria, Kolding et al. 2014). Aside these few examples, the literature on the negative externalities created by inland capture fisheries is overall scant compared to that on the negative impacts of marine capture fisheries (Cooke et al. 2014).

Freshwater aquaculture

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 percent of the world's freshwater aquaculture production comes from Asia (FAO Fishstat online query, 2015), following a rapid increase in production in the last 30 years (Figure 3).

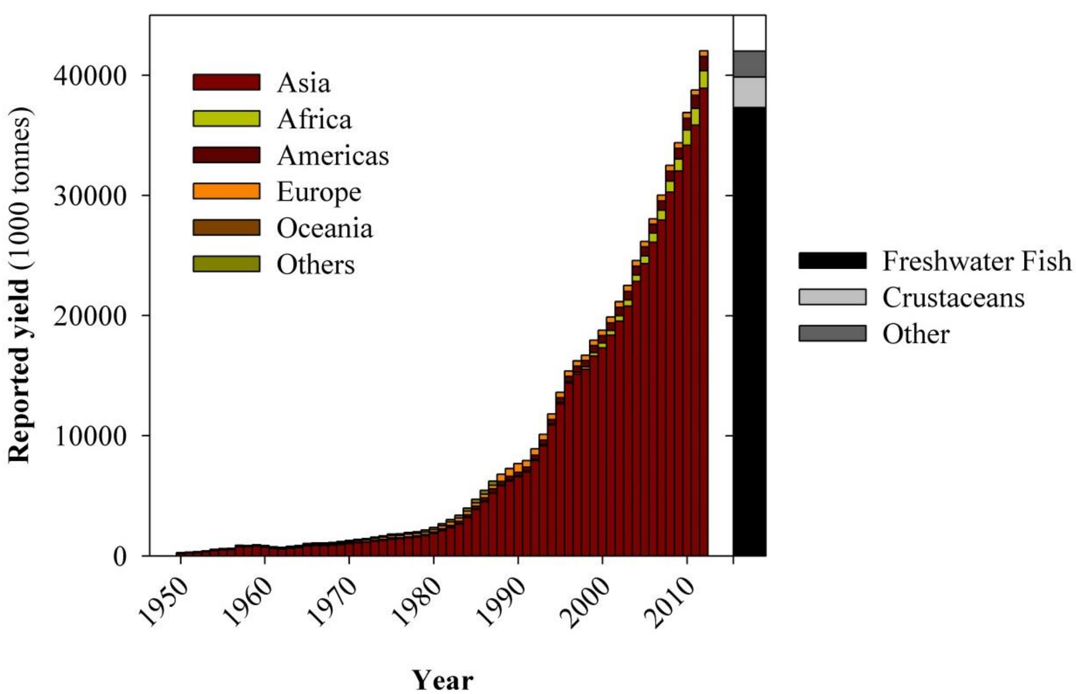


Figure 3: Global reported aquaculture production from inland waters (fresh and brackish waters environments) for 1950-2012 and species composition of the production for year 2012 (left bar). Others includes: diadromous fishes, aquatic animals, molluscs, marine fishes and aquatic plants (source: FishStat J 2014)

Hambrey et al. (2008) provide a thorough review of freshwater aquaculture systems' impacts on ecosystems functions and services, such as habitat conversion from the development of aquaculture farms, release of farm nutrients in the environment, use of chemicals in intensive operations, introduction of alien species, escapes and genetic interactions with native species, and interactions with capture fisheries. Relying on complementary information from case studies representing the wide range of freshwater fish production systems around the world, their analysis of the severity of these impacts remains however inconclusive, owing to the multiplicity of factors which 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. While a significant proportion of marine and brackish water aquaculture production is destined to export markets and foreign revenue generation, freshwater aquaculture products remain primarily for domestic markets, and therefore a critical element in the food security of producers and local consumers (ibid). Cultured catfish and tilapia, however, are also two commercially important freshwater species on global markets: catfish culture in Viet Nam is now largely export; tilapia is exported to Europe and the United States.

As is the case of inland capture fisheries, aquaculture production systems are classified in many different ways, whether one adopts a production standpoint (e.g. extensive, semi-intensive, intensive) or an economic one (e.g. small-scale, large-scale, industrial, commercial, subsistence). Because there is no agreement on the specific characteristics of the systems encompassed in these categories, production data is not disaggregated according to these.

Broad typology of freshwater fish production systems

Inland capture fisheries and freshwater aquaculture production systems comprise[12] five broad types of systems:

- Lake and reservoir capture fisheries and culture-based fisheries
- Riverine fisheries (including the floodplains)
- Cage aquaculture
- Pond and raceway aquaculture
- Integrated rice-fish farming

As was highlighted above, these systems vary in production intensity (in terms of size, output, inputs), objectives (for domestic, recreation, as well as export markets and foreign revenue generation) and stakeholders (industrial enterprises, small-scale independent producers, disadvantaged groups, women etc.), generating a huge spectrum of fish production systems with an equally diverse range of social, economic and environmental impacts. Recirculating systems are included under pond and raceway culture and allow for more intensive aquaculture. Despite the multiple ways in which types of inland capture fisheries and

[12] Notably other aquatic habitats (e.g. swamps and peatlands) are also used by capture fisheries but at a lower scale than lakes, reservoirs and rivers (including floodplains).

freshwater aquaculture can be classified, this typology is adopted because it allows linking fish production systems with the management of the bodies of water hosting them, thereby allowing to better comprehend the trade-offs and multiple impacts arising out of the management of aquatic ecosystems and development of fish production.

In sections that follow we attempt a 'finer grain' analysis of these systems' impacts on the ecosystems within which they are embedded, using available literature.

3.1.1 Lake and reservoir capture fisheries and culture-based (enhanced) fisheries

Capture fishing takes place in lakes and reservoirs all over the globe[13]. In these systems a large variety of fishing methods and levels of exploitation is found (Welcomme 2001, Welcomme 2011). As with all capture fishing activities, the level of yield obtainable in these systems is ultimately based on the diversity and stocks of wild fish (biomass) and their annual productivity. These parameters are in turn dependent on a variety of factors, which include: water hydrology and chemistry (e.g. water oxygen levels), water temperature, the underlying productivity of the aquatic system (e.g. primary production) and fishing effort (Welcomme and Hagborg 1977). Fish populations in lakes and reservoirs are generally divided into either pelagic (living in the water column) or demersal (living along shores and bottom) and according to the different fishing techniques employed to capture the different groups. Reservoir fish assemblages are typically associated with those of the host river (Welcomme 2011). The bulk of the estimated production in these systems come from small-scale fishers in developing countries and recreational fishers in industrialized countries and this is seldom recorded in official statistics (Welcomme 2011, Bartley et al. 2015).

Main risks associated with capture fisheries in lakes and reservoirs are changes in biodiversity, through selective fishing or overall high fishing pressure (Welcomme 1996). As tropical systems have a higher biodiversity than temperate systems, the impacts of habitat degradation on biodiversity are greater in the former (Amarasinghe and Welcomme 2005).

To enhance the productivity of lakes and reservoirs, either in a natural or in a degraded state, stocking of fish can be used as a mitigation measure. Production from these stocked systems is recorded as capture fisheries if there is no corporate or individual ownership of the stocks (if there is ownership, the stocked fishery is often recorded as aquaculture, as in the case of China). Stocking is also used to restore the natural productivity of floodplains that have been heavily modified (Bartley et al. 2015) and to strengthen populations of endangered species (e.g. eels in Sweden (Wickström and Sjöberg 2014) and sturgeon in the Caspian Sea (Abdolhay 2004).

Stocking that also involves a certain degree of management of the stock and water body is called culture-based fisheries[14]. This practice is becoming increasingly popular in Asia and specifically in smaller lakes and reservoirs where a certain degree of management can be obtained over the released fish. As the fish is harvested from these natural systems (although enhanced) using capture fishing techniques, the production is recorded as capture fisheries. The hybrid status of culture-based fisheries confuses data reporting and statistics: some countries report catches

[13] Although the majority of the global lake area is in northern temperate zones (Verpoorter et al. 2014).
[14] A culture based fishery is: "A fishery in which the use of aquaculture facilities is involved in the production of at least part of the life-cycle of a conventionally fished resource; aquaculture is usually the initial hatchery phase that produces larvae or juveniles for release into natural or modified habitats" (FAO 2015).

under 'aquaculture' (e.g. China), others which used to record it as aquaculture have switched to record it as capture (e.g. Mexico) (Bartley et al. 2015). This has major implications for the management of the concerned water bodies.

No global record of catches from lakes and reservoirs is available: in the FAO fisheries production database (FishStat J 2015), production is not reported by aquatic habitat. There is no global record of the amount (volume, number) of fingerlings that are introduced into natural aquatic habitats (lakes and reservoirs, rivers) annually either. Although the positive impact of stocking and management on the productivity of water bodies has been demonstrated in some countries (e.g. Sri Lanka where culture based fisheries is extensively practiced in perennial reservoirs, Chandrasoma et al. 2015), there are no estimates of how much of the global catches from inland waters are originating from stocking programmes.

Main risks associated with stocking programs and culture based fisheries, are concerns about the potential risks associated with stocking and introducing fishes, particularly with respect to ecosystem functioning, changes in community structure and, losses of genetic integrity and cost effectiveness (Thorpe et al. 2011, Nguyen 2015).

Impacts of lake and reservoir fishing on the surrounding ecosystem are well studied and understood for some ecosystem services (e.g. food provisioning and biodiversity), whereas other services are either not well studied or the relevant studies are not carried out within an ecosystem services framework. Box 1 provides a snapshot review of studies that have considered the services provided by inland freshwater fisheries, whilst **Error! Reference ource not found.** considers those supplied by fish stocking schemes.

Box 1: A snapshot review of the services of inland capture fisheries

Fish populations can support a substantial proportion of primary production (up to 51 percent) in reservoirs (Vanni et al. 2006) and control unwanted pest species, especially vectors of water-borne diseases thanks to predation on mosquito larvae (Cowx and Portocarrero Aya 2011).

Species shifts in the fish population can affect water quality parameters, for example through top down effects on the lower levels in the food web. Notable examples of this are the increase in income and fish catches of more valuable species using biomanipulation with additional positive effects on water quality, e.g. increased water clarity and decreased nutrients (Lin et al 2015, Angeler et al. 2003). Common carp (Cyprinus carpio) has been shown to decrease water quality in a degraded wetland in Spain by increasing turbidity and nutrient concentrations (Badiou and Goldsborough 2015).

Food webs and trophic structures and biodiversity

Lakes and reservoirs fishing can control and maintain biodiversity within the fish population (assemblage), whilst controlling and maintaining diversity of lower trophic level species (e.g. zooplankton) and serving as a food base both externally for many mammalian, bird and reptilian predators, and internally within the fish population between fish species and fish species age-cohorts (Cowx and Portocarrero Aya 2011).

Box 2: Impacts on ecosystem services from fish stocking, including culture-based fisheries (Source: Holmlund and Hammar 2004)

The effects of fish stocking can either stimulate or undermine specific ecosystem services and this depends partly on the ecosystem context. A distinction should be made between new introductions and enhancement of existing fish populations, where enhancements are generally made with the objective of not causing any dramatic changes in ecological functions and thus generate minor changes to ecosystem services.

New introductions can result in increased water clarity (e.g. biomanipulation) and create new recreational or commercial fisheries. The practice of introducing species is common and Asia and Europe have the highest levels of total introductions and introductions from outside the region (see insert table). Although country movements are omitted here, these are also important and should be monitored and regulated by national authorities (FishBase 2015). The effects of these introductions include cascading food web changes at species level in linked areas and introduction of disease and invasive parasites. There are also possible long-term effects, such as the capacity of the ecosystem to cope and adapt to environmental changes. Examples also include the introduction of alien fish species in Mediterranean freshwaters that was found to negatively affect native fish populations due to competition for resources and habitat degradation (Hermoso et al. 2011).

Global record of transboundary introduction of fish species to inland waters (natural waters and aquaculture) per continent (Source: FishBase 2015).

	Total introductions to region	Introductions from elsewhere to the region (with unknowns)	Introductions from elsewhere to the region
Africa	555	350	199
America, North	592	374	152
America, South	207	174	94
Asia	1 317	880	284
Europe	937	708	218
Oceania	296	260	97
Former USSR	209	184	52

Enhancing existing populations is generally done to enhance already existing ecosystem services. However, the released fish may interbreed with the natural population, increasing risks of changes in biodiversity. Regular enhancement may also mask the over-fishing of declining wild fish resources. In addition, mixed fish stocks can be problematic to use as ecological change indicators because wild fish is difficult to discern from hatchery raised fish.

3.1.2 Riverine and floodplains capture fisheries

Rivers and connected wetlands (e.g. floodplains) are widespread globally but most of the largest river systems are found in the tropics (Lehner and Döll 2004). Rivers and connected wetlands are often used for capture fishing activities, which depend largely on the wild fish stocks that are naturally maintained by these systems. Many fish populations in river systems are, in contrast to lake fish populations, migratory, either longitudinally (along the river) or laterally (from river into surrounding wetlands). Fish populations also migrate from rivers into the sea where they can sustain a substantial fishery (e.g. salmon). Stocking is also a common practice in many river systems, especially as mitigation measure after hydropower development (e.g. salmon) but also to strengthen threatened populations (e.g. Mekong giant catfish).

In rivers, fishers exploit the diversity of habitats, the many species, and the seasonal conditions, using a range of gears adapted to the capture of the various exploited species and life stages (Welcomme 2011).

Many of the large tropical river systems (e.g. Mekong, Irrawaddi and Amazon) are very productive in terms of fish landings, and a diverse set of techniques is used to harvest these resources. In the Mekong River, the annual fluctuations of water into the Tonle Sap result in massive fish production that is harvested during both small-scale and large-scale fixed gear fishing activities

Figure 4). Impact assessments of riverine and floodplains capture fisheries on the surrounding ecosystem are however scarce.

Figure 4: An aerial view of the upstream bag net anchor geeat and bag nets of Tonle Sap Dia #5, 10 km north of Phnom Penh during the peak trey riel run, January 2005, Kandal Province, Cambodia.
Source: Garrison Photographic.

River fisheries also form a large part (and value) of recreational temperate fisheries, e.g. fishing for salmon and trout. Generally, recreational fisheries are not recorded in the official statistics reported to FAO. There is growing evidence that recreational fisheries are having significant impacts on fish stocks, through both fishing pressure and stock dynamics (Cooke and Cowx 2004). Recreational capture fisheries are however unique in the way they provide cultural and social services.

3.1.3 Cage aquaculture

Cages are typically sited in larger water bodies such as lakes and reservoirs that have sufficient depth for the cages (Beveridge 2008), but are also found in marine environments. Attempts to locate them in irrigation canals have also been made to encourage multiple uses of water, but are not widespread owing to technical, biological and water management difficulties (Li et al. 2005). Many factors must be considered for the selection of suitable sites: climatic conditions (e.g. winds, precipitation, temperature), hydrographic conditions (e.g. depth, currents), water quality (e.g. dissolved oxygen, pH, temperature) as well as water retention, flows and management (in particular in the case of man-made reservoirs) (Beveridge 2008).

Flexibility in the choice of materials, including low-tech locally available ones, increases the adaptability of cage aquaculture to many contexts, provided these are suited to environmental conditions and are within the economic reach of those engaging in cage farming

Figure 5).

Figure 5: Examples of freshwater cage aquaculture.
[a] Crowded cages in Lake Taal, Philippines.
[b] Freshwater fish raised in cages in eutrophic Cirata Reservoir, West Java, Indonesia.
[c] Large-scale commercial cage culture of *Oreochromis shiranus*, Lake Malawi.
Photos courtesy of P. Edwards.

Net pens, which are enclosures anchored to the substrate, are a type of cage that does not depend on deep water. They are often used to raise juvenile fish, e.g. tilapia hapas, before the transfer of these fish to cages, ponds or raceways for grow-out.

There are no readily available production statistics for cage aquaculture production (Tacon and Halwart 2007). Statistics for freshwater cage aquaculture production are even more difficult to compile, with Tacon and Halwart's data the only source of global information on the sector. Table 3 provides an overview of the quantities and origin of the main freshwater species produced in cages. The production is dominated by Pangas (41.1 percent of total), Tilapia (31.8 percent) and carps (6.6 percent).

Table 3: Top ten freshwater cage aquaculture producers in 2005

Country	Quantity (tonnes)	Percent of total (%)
China	704 254	68.4
Viet Nam	126 000	12.2
Indonesia	67 672	6.6
Philippines	61 043	5.9
Russian Federation	14 036	1.4
Turkey	10 751	1.0
Lao People's Democratic Rep.	9 900	1.0
Thailand	7 000	0.7
Malaysia	6 204	0.6

Japan	3 900	0.4

Source: Tacon and Halwart (2007)

The negative environmental impacts of cage aquaculture have been extensively documented in the case of key marine species such as salmon (see Tacon and Halwart 2007, and Grøttum and Beveridge 2007 for a thorough review). On the other hand, studies of impacts of freshwater cage aquaculture on the surrounding ecosystem are scarce, and sometimes contradicting. Box 3 provides a snapshot of the situation, based on a review of the little literature available. It suggests that when negative impacts are caused by freshwater cage aquaculture, these are as much dependent on the style of management and farming, as on the prevailing conditions – in particular ecological and hydrological characteristics of the lake or reservoir – where cage production is taking place. Negative externalities arising out of the overcrowding of cages and consequent deterioration in water quality are usually not considered beyond the negative consequences this has on fish production itself. If conflicts over the spatial occupation of water bodies by cages are mentioned, it is always in passing and not detailed enough to draw meaningful conclusions over the creation of such externalities on transport, capture fishing and other possible uses of the space and water resource. Similarly, from a social and institutional perspective, inequalities and conflicts created by cage aquaculture may be more often the result of exogenous factors such as poor planning, weak enforcement of regulations and inadequate targeting of beneficiaries, than created by the production of fish itself.

Box 3: A snapshot review of the impacts of cage aquaculture.

Impact on water quality: +/-

Over-concentration and poor siting of cages in reservoirs and intensive production are known to have been an important cause of eutrophication in reservoirs (e.g. Indonesia: Costa-Pierce 1998). It remains a threat today when policy decisions on reservoir occupancy and production targets are likely to exceed reservoirs' carrying capacity (e.g. Brazil: David et al. 2015). The impact of lower intensity production on water quality, for example small-scale tilapia cage culture as studied in two different parts of Africa (in Lake Volta, Ghana, and in Ethiopia), appears however to be minimal (Ofori et al. 2010, Defegu et al. 2011). This however contrasts with a case of tilapia cage culture in a hydroelectric reservoir in Sarawak, Malaysia, where the impact on a majority of water quality indicators (lower pH, higher turbidity, conductivity, TSS, BOD5 and chl-a) was significant (Nyanti et al. 2012). Evidence of the impact of rainbow trout production intensively farmed in cages in lakes in Canada is mixed (Azevedo et al. 2011), suggesting that, above all, lake size, ecology and hydrographic characteristics and prevailing conditions (e.g. winds etc.) play a pivotal role in the dispersal of nutrient loadings and therefore in the mediation of the impact of cage culture on water quality.

Impact on local aquatic biodiversity: -

The threat to biodiversity comes with the introduction of non-native species as farmed stock, and from the omnipresent risk of interactions between farmed escapees and local native flora and fauna. Although evidence of such interferences and impacts on local biodiversity is scant, the threats associated with the introduction of a non-native, invasive species such as tilapia and carp as species of choice for cage aquaculture production in Brazilian reservoirs are deemed high (Pelicice et al. 2014). Also in Brazil, feed loss and interferences with populations of micro-crustaceans have been shown to alter the feeding behaviour of local, endemic fishes sharing the same habitat (Demetrio et al. 2012). Similarly, non-native salmon escapees from intensive cage farming operations in Chile's Patagonian lakes were shown to have contributed to a decline in the abundance of native fishes through predation (Arismendi et al. 2009).

Social and economic impacts: +/-

Cage aquaculture has been used a means to provide employment and livelihoods for people displaced by hydroelectric dams. The development of the Sagulin reservoir, Indonesia, for this purpose in the 1990s turned out to be a mixed success. Although generating much needed income, employment and large quantities fish, the benefits of cage aquaculture were unequally appropriated across social groups as a result of poor planning and weak enforcement of regulations, as well as inadequate extension and support promoting sustainable farming practices to farmers (Costa-Pierce 1998). This story contrasts with the livelihood support benefits (e.g. fish as food, disposable income for clothing and children's education) that have been experienced in displaced and deprived fishing communities following the introduction of small-scale tilapia cage farming in Nepalese hydroelectric reservoirs (Bista et al. 2009) and in Lake Volta (Ofori et al. 2010), despite the relative low productivity of these production systems (4.3 kg/m3 in Nepal, 9.6 kg/m3 in Ghana). This highlights once again the need to discern not only production scales and intensities, but also – and perhaps even more importantly - the way in which such developments are planned and promoted and the extent to which they adequately integrate biological, technological and ecological considerations alongside social and institutional ones.

3.1.4 Pond aquaculture

Pond culture refers to the breeding and rearing of fish in natural or artificial basins. It is the earliest form of aquaculture and dates back to the era of the Yin Dynasty, between 1400 and 1137 B.C. (Baluyut 1989). Today, it is the most widespread aquaculture system. Designs range from earthen ponds of various dimensions filled and emptied by gravity or pumping, to raceways and intensive recirculated systems with minimal water exchange with the surrounding environment. Whilst ponds can be used to culture a wide variety of organisms, production from freshwater, and to a lower extent but with some country variations, brackish water environments, are dominant (Verdegem and Bosma 2009, Table 4).

Table 4: Pond area, production and average pond production in freshwater and brackish water culture environments for a number of selected countries (Source: Verdegem and Bosma 2009 and references therein).

Country	Environment	Pond area (ha)	Production (tonnes/year)	Mean production (kg/ha/year)
Bangladesh	Freshwater	151 000	358 115	2 609
	Brackish	203 071	114 660	565
China	Freshwater	5 583 276	5 091 330	7 530
	Brackish	676 184	34 272	3 000
Cuba	Brackish	1 383	830	600
Czech Rep.	Freshwater	41 000	20 000	450
Egypt	Freshwater	64 100	240 000	3 744
Hungary	Freshwater	28 000	10 764	384
India	Freshwater	850 000	1 870 000	2 200

Indonesia	Freshwater	97 821	378 378	3 868
	Brackish	480 762	501 977	1 044
Nepal	Freshwater	6 000	18 060	3 000
Total and mean, incl. China	**Freshwater**	**6 832 621**	**20 712 323**	**3 031**
	Brackish	**1 361 400**	**5 708 797**	**4 193**
Total and mean, excl. China	**Freshwater**	**1 249 345**	**2 929 589**	**2 345**
	Brackish	**685 216**	**617 467**	**901**

Large and small-scale operations vary in intensity, depending on supplementary inputs provided. In small-scale operations, ponds are often integrated with other forms of animal production (e.g. poultry) and agriculture (e.g. supplementary irrigation of homestead gardens and crops). This generates many benefits in terms of nutrient recycling in agro-ecosystems (Little and Edwards 2003) (Figure 6). Pond aquaculture also provides an additional source of income and food for millions of small-scale farmers, in particular in Asia (Nhan et al. 2007). The development of pond aquaculture is currently gaining momentum in Africa, with Egypt and Nigeria as main producers (FAO 2014) but there is also growth in aquaculture production tanks located in peri-urban areas near large markets in Nigeria (Miller and Atanda 2011) and integrated aquaculture—agriculture systems in Malawi and Cameroon (Brummett and Jamu (2011). In addition, in places where pond aquaculture is a traditional activity, such as in China, ponds are an important feature of the landscape and form part of the cultural heritage of the country.

Figure 6: [a] Crop fertilization with pond mud, Bangladesh.
[b] An integrated poultry-fish pond system, North Viet Nam.
Photos courtesy of P. Edwards.

A major issue with pond aquaculture is the maintenance of good water quality, which is most critical with the intensification of pond production (Boyd and Tucker 1998). Negative environmental impacts of freshwater pond aquaculture relate essentially to risks of water pollution through release of pond effluents, depending on pond design, drainage and water management, and if it is fertiliser-based pond production (Boyd and Li 2012, Boyd and Tucker 2012).

Pond aquaculture can also impact on biodiversity: directly, depending on the land area used, species used (exotic or not), use of captured fish to feed cultured fish; and indirectly depending on the modification of the aquatic ecosystem through effects on water quality and escapees, with subsequent modification of local fauna and flora (Bosma and Verdegem 2011). Despite its potential for integration with other food producing activities, pond aquaculture requires large quantities of water (withdrawn and consumed) and potentially competes with other uses of water in water scarce areas. It can also put pressure on water groundwater and soil resources if the percolation water contains harmful substances (Bosma and Verdegem 2011).

3.1.5 Rice-fish farming

Over 90 percent of the world's rice, approximately 194 million hectares, is grown under flooded conditions which, with some relatively simple modifications in the design of rice fields allowing water retention for sufficient periods, provides a suitable habitat for the growth of fish and other aquatic organisms (Halwart and Gupta 2004). There is however no readily available global statistics on quantities of fish harvested from rice fields. In China, where the traditional practice has been promoted through government programmes, rice field areas with fish culture doubled between 1990 and 2007, and the contribution of rice-fish culture to inland aquaculture increased from 3.5 percent to 6 percent over the same period (Weimin 2010). Cyprinids and tilapias are the two groups of fish species most often stocked in rice fields (Figure 7).

Figure 7: Red common carp integrated with rice, China.
Photo courtesy of P. Edwards.

The benefits of rice-fish farming are relatively well documented and have been shown to be positive and significant from an ecosystem services perspective (see **Error! Reference source ot found.**). In particular, paddy fields host a rich diversity of aquatic animals. Around 100 species additional to rice are naturally present in this ecosystem and are used for food, medicine and ceremony (Halwart 2006, Halwart and Bartley 2007).

Although the practice is promoted as a means to increase food production and water productivity, management issues seem to constrain its more widespread adoption, with only one percent of paddy fields currently used for the integrated production of rice and fish (Bartley et al. 2015). Rice-fish farming is indeed sensitive to the intensification of rice farming such as increased use of pesticides and implementation of water saving methods, which translate into a loss (though un-quantified) of fish output (de Silva et al. 2013). There are also important trade-offs arising out of the expansion of wet rice cultivation, notably in terms of release of large amounts of methane this causes (Robin and Wassman 2003). This suggests that cultivating fish in all rice fields may not be a panacea unless rice farming as a whole evolves towards "ecosystem-based agriculture" (Lansing and Kremer 2011)[15].

Section 3.3 and the case studies in Part 2 will delve in greater depth in the relationships between fish production and ecosystem services.

Box 4: A snapshot review of the impacts of rice-fish farming

Impact on rice and fish output (food provision): +
Yields of rice from integrated rice-fish culture are equivalent to those obtained in rice monoculture (Xie et al. 2011). Protein output, however, is much higher from rice-fish fields than rice only fields (Xuegui et al. 1995). For example in China, with the stocking of 3 000-12 000 fingerlings, 450-750 kg of fish can be obtained without supplementary feeding (Weimin 2010). This constitutes an important source of animal protein in remote communities.

Impacts on local ecology and biodiversity: +
Fish acts as a bio-control of agents in rice (e.g. insect pests, disease and weeds), which emphasises mechanisms naturally occurring in ecosystem and enables a significant reduction in pesticide use (68 percent) and chemical fertilizer (24 percent) (Xie et al. 2011). Rice fields enable to maintain high levels of aquatic biodiversity (Halwart 2006).

Impacts on nutrient cycling: +
Fish in rice fields contributes to the recycling of nutrients through feeding and depositing faeces in the soil. By swimming about and disturbing the soil-water interface, fish enables the release of nutrients such as nitrogen and phosphorus, which facilitates their uptake by rice plants (Cagauan et al. 1993, 1995, cited in Halwart and Gupta 2004).

Social, cultural and economic impacts: +
In China, the usual net income from well-managed rice-fish culture is US$2 000-4 000/ha, which corresponds to a two to four fold increase from a sole rice crop (Weimin 2010). This is particularly significant in areas where opportunities for additional income generation are limited (ibid). Rice-fish culture has also been shown to have positive and significant impacts on the welfare of indigenous farmers in Bangladesh, measured in terms of household annual income, farm income and quantity and frequency of fish consumption (Saiful Islam et al. 2015). This confirms findings from previous studies in the same country that not only could rice-fish farming increase farmers' profits (three times higher compared to a monoculture of rice), it could also increase household fish intake by 14 percent and provide additional employment opportunities (Rahman et al. 2012), and that adopters of this form of integrated pest management experienced income benefits compared to non adopters in Vietnam (Berg 2002).

Rice-fish farming is an ancestral activity in much of Asia, forming an integral part in the cultural heritage of many rural societies (Xie et al. 2011). This confers them an important status, which has led to the official recognition of rice-fish farming systems by FAO and UNESCO as a "Globally Important Ingenious Agricultural Heritage System"(Lu and Li 2006).

3.2 Geographic coverage, global production and trade patterns and distribution of beneficiaries of inland fisheries/aquaculture production

[15] Such aspects may be addressed in greater depth under the TEEB-Rice feeder study carried out in parallel to the present one.

3.2.1 Geographic coverage, global production and trade patterns

Based on officially reported figures to FAO, the main production center for inland capture fisheries is Asia followed by Africa (section 3.1.1), and Asia for inland water aquaculture (section 3.1.2). Notable inland capture fisheries systems are the Mekong River, Irrawaddy River, Brahmaputra River (including tributaries and connected floodplains) and Lake Victoria – correspondingly many of the riparian countries of these rivers and lakes are among the main producing countries (Table 5). High production from China and India can be attributed to many different aquatic systems (rivers and reservoirs) as well as to their relative large size and population compared to the other countries, which gives them comparatively lower catches by water area. The relative low production per water area value from Brazil can be attributed to the large Amazon River area.

Table 5: Main inland capture fisheries producing countries in 2012

	Country production **(tonnes)**	Production/water area[1] **(kg/ha)**
China	2 298 199	22.3
India	1 460 456	14.4
Myanmar	1 246 460	88.8
Bangladesh	957 095	80.1
Cambodia	449 000	63.5
Uganda	407 638	76.3
Indonesia	393 553	11.1
Tanzania, United Rep. of	314 945	32.2
Nigeria	312 009	33.4
Brazil	266 042	4.4
Other (n= 137)	3 525 283	11.2[2]
Total	11 630 680	9.6

[1] **Water area = $GIEMS_{max}$ (Fluet-Chouinard et al. 2015) / [2] Average values**

The bulk of the reported production (95.5 percent) from inland capture fisheries are produced in least developed or developing countries (Table 6) and consumed locally (World Bank et al. 2010), with certain notable exceptions, e.g. Nile Perch from Lake Victoria (Eggert et al. 2015). The picture is almost the opposite when looking at marine capture fisheries, where only 6.6 percent of the total production is produced in the least developed countries. In fact, 45 percent of the reported fish production in the least developed countries is coming from inland fisheries.

Table 6: Provenance of capture fisheries production in 2014 (Source: FishStat J)

	Inland		**Marine**		
Country groups	**Production** (tonnes)	**Percent per country group**	**Production** (tonnes)	**Percent per country group**	**Percent inland of total production**
Least developed	4 703 935	40.2%	5 353 158	6.6%	47%
Other developing	6 439 875	55.1%	51 628 877	63.9%	11%

Developed	543 697	4.7%	23 819 769	29.5%	2%
Total	**11 687 507**	**100.0%**	**80 885 079**	**100.0%**	**13%**

Data exclude whales, seals, other aquatic mammals and aquatic plants.
The aggregate "Total, Marine" includes also 83 275 tonnes of not identified countries, data not included in any other aggregates.

Main freshwater aquaculture production centres are China followed by India, Viet Nam, Indonesia and Bangladesh (Table 7).

Fish is one of the most traded food commodities, ahead of wheat and rice. However, global trade patterns in fish products are usually studied in the context of marine capture fisheries (e.g. Swart et al. 2010), much more rarely in the context of inland capture fisheries. Yet it is estimated that, in general, products from freshwater aquaculture are traded to a much larger extent than those from inland capture fisheries, for example the Vietnam farmed catfish industry that is globally traded versus the highly productive capture fisheries in the region that are locally bartered or consumed (Belton et al. 2011).

Table 7: Main freshwater aquaculture producing countries in 2012 (Source FishStat J)

Country	Production (tonnes)
China	26 517 693
India	3 847 848
Viet Nam	2 140 900
Indonesia	2 101,874
Bangladesh	1 575 306
Egypt	1 017 738
Myanmar	826 944
Brazil	612 647
Thailand	408 944
Philippines	310 054
Others **(n= 161)**	2 382 321
Total	**42 028 692**

However, in areas where inland fisheries is highly developed and aquaculture less so, such as in Lake Victoria, inland capture fishery products are traded to a larger extent (FAO 2014). Table 8 shows the value of the global trade flows of freshwater fish and fish products. However, these general patterns mask wide variations in the market value of individual freshwater species: cichlids, Nile perch and eels can fetch higher prices on export markets than carps and cyprinids. Although some species are important export commodities destined to mass or niche markets (e.g. Nile perch and eels respectively), most other species are predominantly traded on domestic markets and play a fundamental role in local food security.

Table 8: Total value of freshwater fish and products trade in 2011, in 1000 US$ (Source: FishStat J)

Trade flow	2011

Export	24 639 556
Import	22 810 108
Re-export	31 080
Total	**47 480 744**

3.2.2 Distribution of beneficiaries and nutritional benefits

Globally, some 70 percent of the world's population lives within five kilometers of a surface freshwater body (Kummu et al. 2011, Figure 8). Notwithstanding differences between temperate/cold and arid zones (80 percent and 55 percent respectively) related to the presence of water bodies and variations in population densities in temperate and arid areas, one may safely assume, on the basis of what was said previously on fishing-based livelihoods and prevalence of local consumption and domestic trade patterns in freshwater fish, that this is an influencing factor in the nutrition and food security of people living in the relative vicinity of these water bodies. In addition to this, inundation areas (Figure 9) provide a supplementary habitat for capture fisheries and extensive aquaculture, when flooded areas are fenced off to retain water beyond the flooding period, allowing the rearing of the aquatic organisms that have been captured (e.g. 'finger ponds' around Lake Victoria, Kipkemboi et al. 2010).

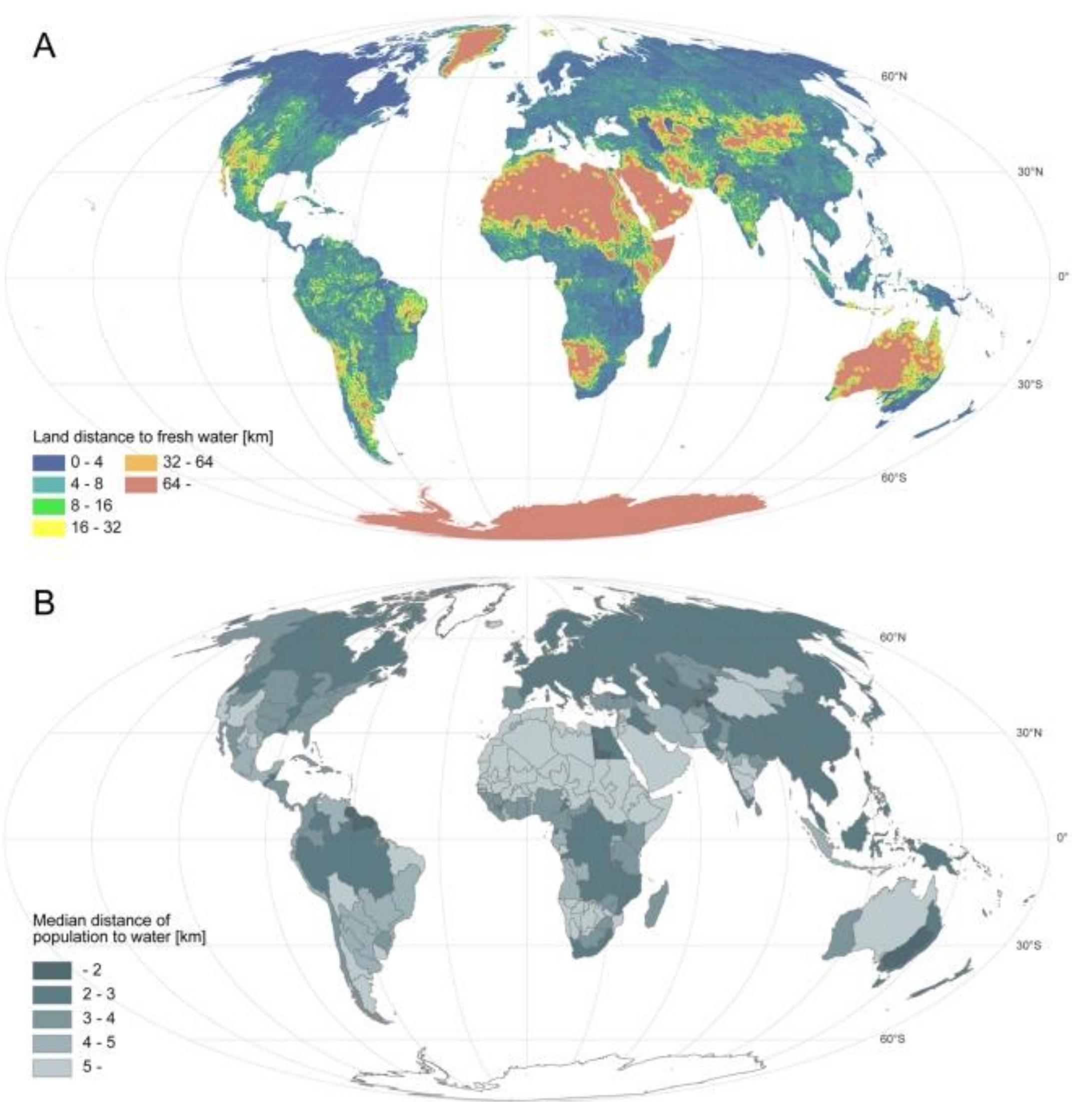


Figure 8: Distance to water. A: Average land distance to fresh water for each square kilometre of land. B: Median distance of population to water at FPU (Food Production Unit) scale (Source: Kummu et al. 2011).

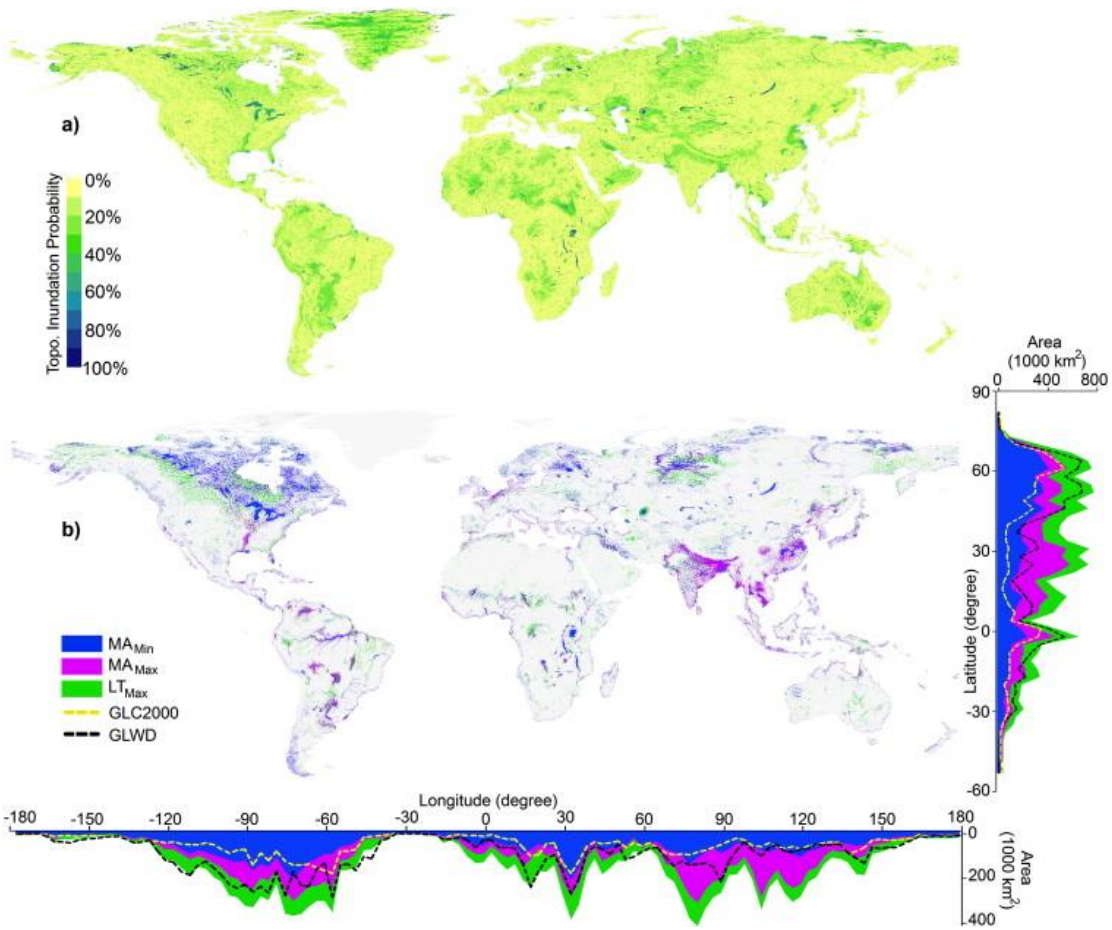


Figure 9: Global inundation map (Source: Fluet-Chouinard et al. 2015). (a) Global inundation probability map. (b) Three states of inundation (minimum inundation area MA_{Min}, maximum inundation area MA_{Max}, and long-term maximum inundation area LT_{Max}).

Lakes, reservoirs and rivers contribute to the global nutrient requirements of human populations (Lymer et al. 2016b). Using data on catches for a global set of specific lakes, reservoirs and rivers, and combining them with global habitat specific water area, an estimated theoretical potential yield can be estimated (Lymer et al. 2016a). Similarly, combining the global mean fish biomass and fish production (Table 9) with the specific global habitat area will give an estimated global biomass and yearly production of fish annually (Figure 10).

Table 9: Global mean freshwater fish biomass and production in lakes, reservoirs and rivers with 95 percent confidence interval (95% CI)

	Global mean biomass **(kg/ha)**	*95% CI*	Global mean production **(kg/ha/year)**	*95% CI*
Lakes and reservoirs[1]	88.7	*15.1*	71.8	*41.4*
Rivers[2]	176.0	*47.6*	244.7	*94.2*

[1] Samarasin et al. 2014 (and references therein), Downing et al. 1990 (and references therein), Bachmann et al. 1996 (and references therein), Emmerich et al. 2012, Randall et al. (1995), Sarvala et al. (1999).
[2] Welcomme 2001 (and references therein), Kwak and Waters (1997), Formigo and Penczak (1999), Randall et al. (1995) (and references therein), Mazzoni and Lobo'n-Cervia (2000) (and references therein).

The global estimates of fish biomass and annual fish production from lakes, reservoirs and rivers are much higher than the recorded catches by FAO member states from inland capture fisheries (Figure 10). There are several reasons for this: 1) not all fish yearly production is captured by fishing but also sustain other ecosystem services; 2) not all suitable lakes, reservoirs and rivers are used for capture fishing; 3) not all lakes, reservoirs and rivers are suitable for capture fishing and 4) not all catch is recorded in official statistics (e.g. recreational and subsistence).

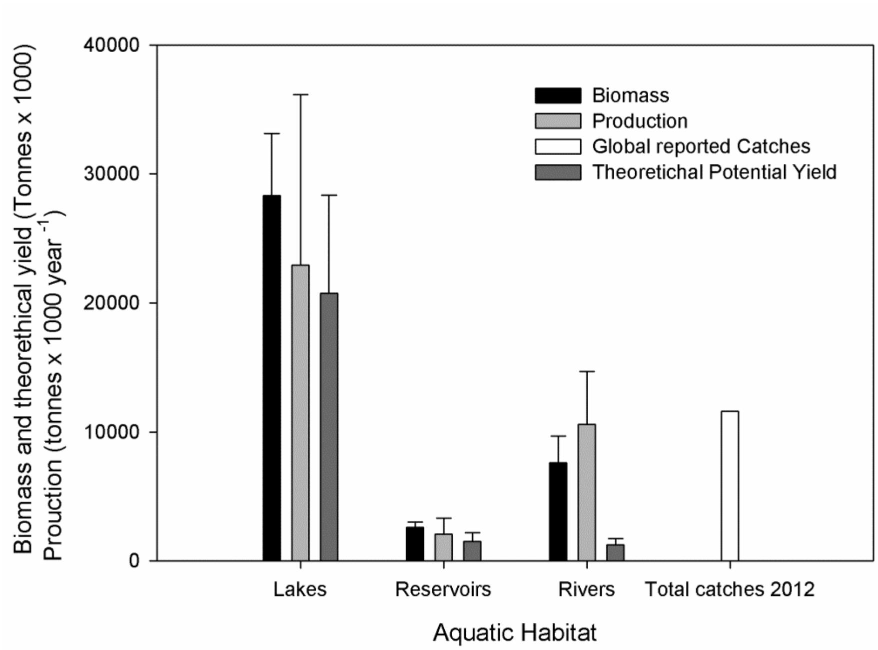


Figure 10: Estimated global fish biomass and yearly fish production for lakes and reservoirs and rivers with theoretical potential yield (Lymer et al. 2016a) and Global reported inland capture fisheries catches (FishStat J) plotted for comparison.

It should also be noted that several other highly productive inland capture fisheries production systems (e.g. rice field fisheries and floodplain fisheries – see section 3.1) are not included. If they were included, it would increase the differences even further between the estimated parameters of biomass, production, theoretical potential yield and the figures of catches/yields officially reported to FAO.

The yearly fish production expressed as the potential contribution to the nutritional requirement for the global population (**Error! Reference source not found.**) shows that, every year, fish populations produce significant amounts of nutrients on a global level, of which a proportion is harvested for human consumption.

Hence, valuation approaches of inland capture fisheries systems have to account for the potential under-reporting of catches/yields from inland capture fisheries. They also have to ensure that multiple and essential benefits in terms of protein and other micro-nutrients for human populations, especially as these may not be readily available from alternative sources of food that poorer population can afford are accounted for in the actual capture and yields values in tonnes of fish.

Table 10: Potential contribution of the global annual production of freshwater fish from lakes, reservoirs and rivers to the nutritional requirements of the global population[1] (Source: FAO)

	Protein (%)	Calcium (%)	Iron (%)	Zinc (%)	Vitamin A (%)
Small freshwater fish species	5.4	10.6	12.5	22.3	33.2
Large freshwater fish species	5.6	4.3	6.5	6.3	4.3
All freshwater fish species	5.3	7.3	9.3	13.8	18.7

[1] To establish the global population's nutrient requirements, the global population by 5-year age group and gender (UN 2014), was multiplied with the nutrient requirements, by 5-year age group and gender for protein (WHO 2002), calcium, Iron, Zinc, vitamin A (WHO and FAO 2004) and the potential contribution was calculated by dividing the nutrient requirements of the global population by the total nutrient contribution of the freshwater fish production.

3.3 Interactions between fish production and ecosystem services

3.3.1 Fisheries and aquaculture's services

The provisioning service of inland capture fisheries and freshwater aquaculture is quantified in terms of fish quantities caught or farmed, with their corresponding market value (e.g. FAO FishStats) and in terms of nutrients (FAO's Food Balance Sheets). Reliance on the marketable and nutritional benefits of marine and inland fisheries and aquaculture as most convenient proxies for the overall value of fish-based ecosystems/production systems is insufficient to reflect their full value and contribution. The other services provided by fisheries and aquaculture (regulating, supporting and cultural) have however been far less documented, owing to gaps in scientific knowledge and difficulties in valuation processes. When they have, it is often on an ad-hoc basis and in very specific contexts, which challenges extrapolations to other areas or systems. Table 11 and Table 12 focus strictly on the services of fish populations and inland capture fisheries and freshwater aquaculture. Examples of the nature of these services and/or key source of information are added in the tables' footnotes.

Table 11: Provisioning, regulating, supporting and cultural services from freshwater fish populations and inland capture fisheries. + Positive contribution to the ecosystem service concerned. – Negative contribution or self-inflicted impact. +/- Mixed contribution.

Provisioning	+/-	Regulating	+/-	Supporting	+/-	Cultural	+/-
Proteins and other nutrients	[1,6] +	Nutrient cycling	[2] +	Biodiversity	+/-	Recreation and tourism	[6] +
Medicinal products	+	Biological regulation	+	Food webs and trophic structures	[3] +/-	Education	+
Income/revenue	+	Sedimentation regulation	[4] +	Ecological balance	+/-	Research	+[7]
Aquafeeds	[5] +	Water quality	+	Aquaculture	+	Cultural and spiritual identity and heritage	[8] +
Jobs, livelihood options	+						
Health, food security	+						

1: UNEP (2010).
2. Larkin and Slaney (1997), cited in Holmlund and Hammer (1999) and UNEP (2010): In North American rivers, marine-derived carbon and nutrients are provided by migrating salmonids through excretion, spawning and carcasses, and help support the production of algae, insect larvae, young salmon and other fish in these rivers.
3. Vanni et al. (1990), cited in Holmlund and Hammer (1999) and UNEP (2010): Fish consumption of plankton, plants, insects, and other fish impacts upon the trophic structure of aquatic ecosystems and so can influence their stability, resilience and food web dynamics. Removal of top predators and herbivores in particular can lead to significant changes in species composition and to ecosystem change.
4. Fuller and Cowell (1985), cited in Holmlund and Hammer (1999) and UNEP (2010): Fish's foraging and spawning activities can change the physical structure of aquatic ecosystems by removing aquatic macrophytes and fine sediment, and displacing invertebrates.
5. Huntington and Hasan (2009). Trash/low value fish fed in aquaculture operations. Potential source of lower-quality feed for livestock (M. Metian, pers. com.)
6. Magnussen and Kettunen (2013), with reference to the long tradition of recreational fishing and induced tourism in the Lofoten Islands of the Barents Sea.
7. There are many ways in which fisheries contribute to research: for example through the opportunities for investigation and knowledge development they offer to scientists, but also as an environmental indicator that can be used for environmental managers as species presence/absence and/or species assemblage can serve as an indicator of the status of the health of aquatic ecosystems.
8. Kulmala et al. (2013): Baltic salmon's migration patterns shaped the annual rhythm of villages, professions and skills and buildings constructed to serve salmon fishing, influencing the way entire communities thought and lived. Other examples include the worship of fish (endangered *Masheer* species) and rivers in India (Dandekar and Thakkar 2015) and the reserved treaty rights to "First Foods" (which include salmon) of the Columbia River Basin tribes (Lumley 2015).

Table 12: Provisioning, regulating, supporting and cultural services from freshwater aquaculture. + Positive contribution to the ecosystem service concerned. – Negative contribution or self-inflicted impact. +/- Mixed contribution.

Provisioning	+/-	Regulating	+/-	Supporting	+/-	Cultural	+/-
Proteins and other nutrients for human consumption	+	Nutrient cycling	+/-	Biodiversity	[3] +/-	Prestige	[5] +
Income/revenue	+	Biological regulation	[0] +	Land-based crop production enhancement	[4] +	Education	+
Jobs, livelihood options	+	Groundwater recharge	[1] +/-			Research	+
Health, food security	+	Carbon fixation	[2] +			Cultural heritage	[6] +
Fingerlings as bait for capture fisheries	[8] +	Local temperature regulation	[2] +			Community cohesion	[7] +

0. This includes the control of pests, e.g. malaria mosquitoes (Howard and Omlin 2008).
1. Groundwater recharge can occur through seepage from ponds (Sharma et al. 2013). "An abundance of ponds in the landscape is considered to positively affect the groundwater recharge (Manson et al. 1968, Allred et al 1971, cited in Boyd and McNevin 2015, p. 116). Better pond management practices, which, on one hand, aim to limit the risk of pond nutrients (e.g. nitrate) leaching to groundwater and conserve water can, on the other hand, curtail the benefit of seepage.
2. Aquaculture ponds can play a role in temperature regulation, fixation of carbon and emissions of O_2. (Li et al. (2011), though the extent to which this happens requires confirmation.
3. The genetic diversity of farmed fish is likely to continue to increase over years to come as the development of aquaculture is still relatively recent (Tisdell 2012).
4. Land-based crop production can be enhanced by using nutrient-rich pond bottom mud or pond water (Wetengere 2010).
5. Pleasure associated with culturing and catching fish and with the prestige associated with being able to offer fish to visiting friends and neighbors or donating it for village/community events (Horstkotte-Wesseler 1999).
6. As part of a place's agro-cultural heritage as in China) (Li et al. 2011, Xie et al. 2011).
7. Provided that a number of conditions are in place, community-based aquaculture development models have been shown to reinforce group cohesion and social harmony (e.g. Nepal: Shrestha and Pant 2012), although, in other contexts, little is known on the outcomes of such management models on conservation and community development (e.g. Western Indian Ocean:

Ateweberhan et al. 2014).
8. Bait for the Nile perch fishery of Lake Victoria (DM Bartley, pers. com – e.g. Clarias catfish farming in Bondo District, Kenya).

Capture fisheries' services tend to be more recognised in the literature. Those supplied by aquaculture production systems are however not well documented, are very location and aquaculture system-specific, possibly in part due to the fact that aquaculture – much like agriculture – is perceived as a production activity only, and has not yet found its place in an ecosystem services perspective. Indeed, it is generally contended that aquaculture generally places greater demands on ecosystem services than provides them (UNEP 2010). Although like agriculture, aquaculture's extensive modification of natural ecosystems is not in question, such a "cultivated ecosystem" nonetheless delivers a range of non-provisioning services, as was shown in Table 12 and supporting footnotes.

Some forms of aquaculture, such as earthen ponds, are also likely to support the delivery of a wider range of other services. However, if the groundwater recharge service from earthen ponds is lost when concrete tanks are used, other services can nonetheless be created in compensation. For example, a recent study in the Mekong (Cambodia) found that the intensive farming of catfish in small concrete tanks had diverted effort away from overfishing in the Mekong River and that water storage generated water and time savings (less pumping, less time spent fetching water), along with opportunities to increase homestead crop production (WorldFish 2014). This example illustrates that trade-offs can result in positive externalities, although in a way that is not always easy to anticipate.

3.3.2 Trade-offs and externalities within fish production systems

Fisheries and aquaculture can create negative externalities on other users as well as on themselves. 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 use of wild fish in diets, it puts increasing pressure on freshwater resources that are required to produce the crops (Pahlow et al. 2015). Many of the crops used in feeding fish are also used as forage for livestock or consumed directly by people (Troell et al. 2014).

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) interacts with native species, alters biodiversity, food chains, production and nutrient cycling (UNEP 2010, Postel and Richter 2003). Such practices, often stemming from skewed market signals, information asymmetries[16], weak governance, poor husbandry or simple ignorance threaten in their wake the maintenance of other final benefits such as livelihood diversity, food security, environmental integrity and rural viability, along with

[16] Information asymmetry is said to occur in transactions where one party has more or better information than the other, creating an imbalance of power and a skewed decision outcome.

traditional knowledge systems that have co-evolved with the adaptation of humans to their natural environment (Berkes et al. 2000). Losses in welfare resulting from unsustainable aquaculture practices have been relatively well documented in the case of brackish (e.g. shrimp) and marine aquaculture (e.g. Phillips et al. 1993, Primavera 1997, Diana 2009), but less in the case of freshwater aquaculture and even less so in the case of inland capture fisheries.

As they remain uncompensated, these externalities are progressively changing the landscape and functioning and productivity of aquatic ecosystems, adding to other drivers of change, such as climate change and increased water withdrawals, which are threatening aquatic ecosystems and the fish production systems they support. Thus, inland fishes are the most threatened group of vertebrates used by humans (Freyhof and Brooks 2011). **Error! Reference source not ound.** illustrates the potential cumulative impact of 'self-inflicted' externalities (over-exploitation, invasive species) with other ongoing direct and indirect external drivers of change on capture fisheries (both marine and freshwater), aquaculture and freshwater resources in general in a temperate country (UK).

Table 13: Drivers of change and their impact on fisheries, aquaculture and water resources in the United Kingdom (Source: UK NEA 2011)

Driver of change	Habitat change	Climate change	Invasive species	Over-exploitation	Pollution and nutrient enrichment
Capture fisheries	↗	↗	→	→	↘
Aquaculture	→	↗	↗	↗	→
Freshwater res.	→	↑	↗	↗	↗

Impact arrows: ↑ strongly increasing trend, ↗ increasing trend, ↘ decreasing trend, → stable.

3.3.3 Drivers of change, trade-offs and externalities from other uses of water

Inland capture fisheries and freshwater aquaculture are often the silent victims of alterations to the aquatic ecosystems they are embedded in by exogenous activities (e.g. dam construction, water abstraction etc.) and other drivers of change (e.g. climate change). "Victims" because decisions regarding other uses of water bodies modify the functions and services of aquatic ecosystems that freshwater fish production systems rely upon. "Silent" because the value of fish production activities is not recognised in these decisions. The negative impacts of water impoundments (dams and reservoirs) on river ecology and fish communities are well documented (UNEP 2010, World Commission on Dams 2000) along with the implications this could potentially have on fish yields, protein supply and overall food security (Orr et al. 2012, Lymer et al. 2016b). Although the impacts of water resources development (increases in dam density, river fragmentation, consumptive water use, human water stress, agricultural water stress and flow disruption) on human water security are negligible or positive, they should be decoupled from those on biodiversity, which tend to be negative. There is a general correlation between the threats to biodiversity and threats to water security, which suggests that investments in water security (including technology improvements) would improve biodiversity (Vörösmarty et al. 2010). Thus, although the cost of wetland restoration may be high in some instances, it is a worthwhile investment over time, especially as far as inland wetlands and lakes and rivers are concerned (UNEP 2011).

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 on other sectors. Although legal measures enabling 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 (Limburg and Waldman 2009), making the externality internalisation process difficult.

Table 14 summaries the impacts freshwater aquatic ecosystems experience as a result of direct and indirect anthropogenic drivers of change.

Table 14: Exogenous drivers of change and their impacts on freshwater ecosystems and inland fisheries (*Source: adapted from UNEP 2010 - adapted from Postel and Richter, 2003)*

Drivers of change	Impacts on freshwater aquatic ecosystems
Dam construction	Alters timing and quantity of river flows, leading to loss of breeding and feeding habitats Alters water temperature, nutrient and sediment transport, leading to mortality of fish and fry Results in loss of floodplain and other wetlands Blocks fish migrations, preventing access to breeding and feeding areas and in time reduces population levels
Dike and levee construction	Destroys hydrologic connection between river and floodplain habitat, so reducing breeding and feeding habitat
Diversions	Reduce river flow leading to loss of breeding and feeding habitat
Draining of wetlands	Loss of key aquatic ecosystems and breeding and feeding habitats for fish
Deforestation/ land use changes	Alters runoff patterns and increases sedimentation leading to loss of fish habitats and mortality of eggs and larvae
Urban encroachment	Reduces habitat and water quality and quantity
Navigation	Diminishes water quality, leading to fish mortality Removes rapids, rocks, deep pools and other physical aspects of rivers that aquatic biodiversity use for a variety of purposes. Leads to changes in composition of plankton and other organisms: alters food chains and changes composition of fish communities
Acid deposition	Alters chemistry of rivers and lakes leading to loss of fish habitat and decline in populations
Climate change	Changes in runoff patterns from increase in temperature and changes in rainfall, leading to changes in flow regimes i.e. flooding and low flows, as well as in breeding and feeding habitats

Lighter shading: Direct anthropogenic driver. Note however that these drivers are themselves resulting from anthropogenic pressures (e.g. population growth and increased demand for space, water, energy, food etc.).
Darker shading: Indirect anthropogenic driver. Although these drivers are also the indirect result of anthropogenic factors (e.g. industrialization leads to increase in CO2 emissions which leads to acid deposition), they are not directly caused by a human intervention.

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, so that the provisioning, regulating, supporting and cultural services delivered by inland capture fisheries and aquaculture systems, either independently or as part of the wider aquatic ecosystem, are accounted for in production activities or in environmental management and protection measures[17].

Overcoming the trade-offs between fish production and other uses of water is however also possible when the multiple uses of water are integrated. After a long-term decrease, inland open water areas (of both natural and artificial wetlands) have been on the increase as a consequence of dam and water storage construction since 2000 (Prigent et al. 2012, Acreman 2012, both cited in Russi et al. 2013). Although the rate of expansion of irrigation networks has slowed down since the 1970s (Faurès 2007), water conveyance canals and channels offer potential for aquaculture development (Fernando and Halwart 2000, Brugere 2006). Capture fisheries have been developed and enhanced in irrigation reservoirs, conveyance and drainage canals and in water bodies established from residual irrigation water in arid areas (Petr 2003). Other forms of integrated agriculture-aquaculture, such as homestead farms using water retained in fish ponds is used to irrigate crops and support livestock and poultry, or rice-fish farming and simple forms of integrated multi-trophic aquaculture (IMTA[18]) which combine the culture of aquatic plants and fish at different levels of the trophic chain (i.e. carnivorous fish at the top of the chain feeding on zooplankton fish feeders feeding on phytophagous fish species feeding on phytophagous and aquatic micro-vegetation (Kumar 1992) have been traditionally practiced. Yet, despite some evidence of minimisation of trade-offs and of the flow of multiple and simultaneous benefits generated, the widespread adoption of such integrated fish production systems is typically constrained by socio-economic and cultural factors and by institutional bottlenecks related to the management of water (fish production is often a 'by-product' and not the production priority) and of the wider agricultural activities (issues of agrochemical use and accumulation in water bodies) (Brugere 2006, Petr 2003).

3.3.4 Fish in the TEEB Agriculture and Food framework

As fisheries was not originally included in the TEEB agriculture and food framework (TEEB 2014), certain adjustments and developments have to be made to accommodate capture fisheries and aquaculture and allow the internalization of the value of all externalities at production, distribution and consumption of agriculture and food systems. The current framework is based on terrestrial production systems and therefore it needs to be amended with aquatic systems to also capture fisheries and aquaculture (Figure 12). Additionally, the following elements, important to fisheries and aquaculture should be added:

- Invisible benefits:
    - Nutrient transfer
- Visible benefits:
    - Recreation
- Invisible costs:
    - Habitat degradation and restructuring (Aquatic habitats)
    - Loss of water quality and quantity
- It is also important to note that only a portion of the total fish biomass (see Figure 11) can be harvested to ensure a spawning population the coming years, which will also support the production of seed for aquaculture and stocking operations.

[17] E.g. for compensatory payments made to users to maintain the functions of ecosystems, e.g. payments for ecosystem services (PES).

[18] The denomination "IMTA" is relatively recent and tends to be more commonly applied to systems set up in the marine environment (Barrington et al. 2009). The principles of the activity however (integration of species at multiple trophic levels) and its objectives to increase water productivity and minimize environmental impacts are however similar regardless of its degree of complexity and whether it is carried out in freshwater or marine environments.

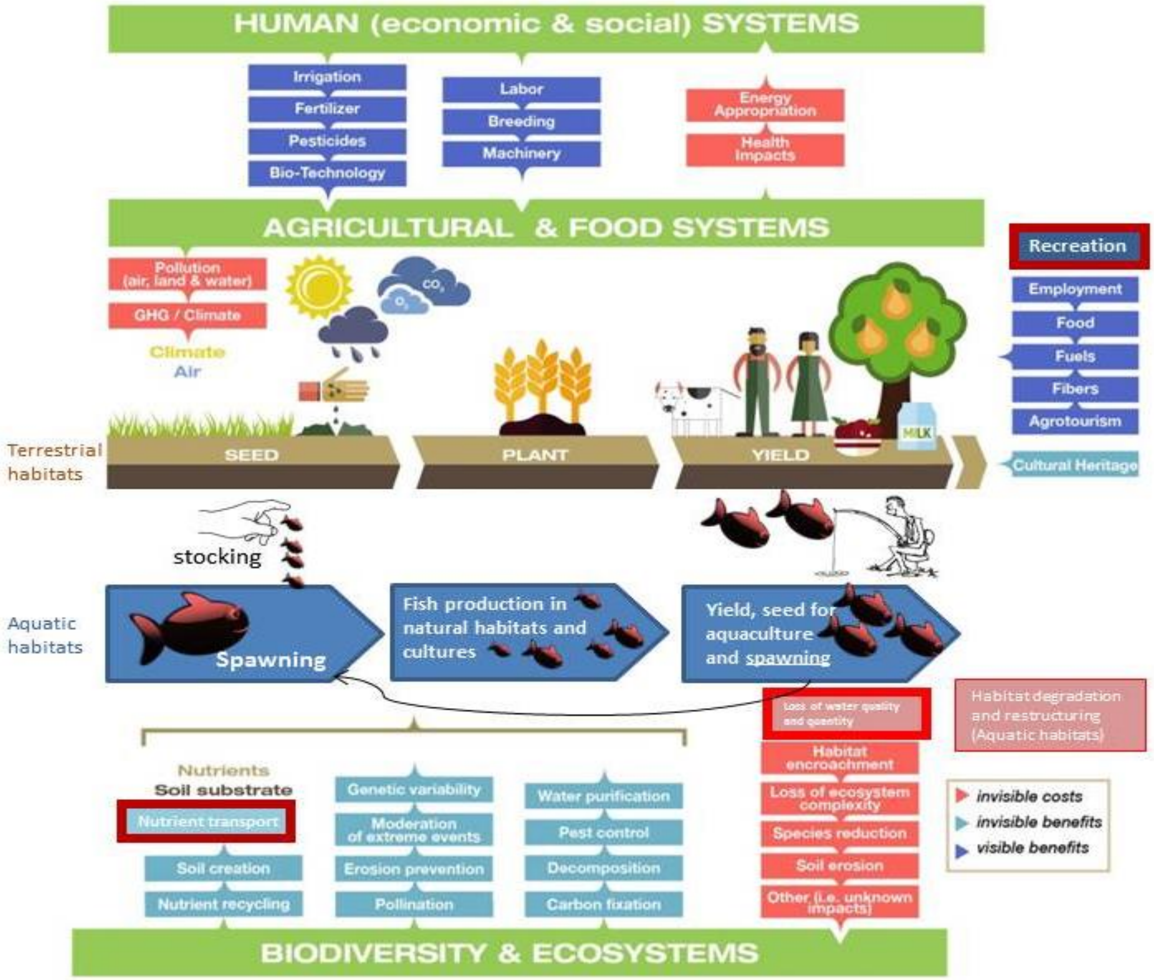


Figure 12. Placing fish within the conceptual 'schematic' of TEEB Agriculture and food (TEEB 2014)

3.3.5 Selection of case studies

Overlaying available world maps of water stresses and biodiversity threats with maps of inland capture fisheries and freshwater aquaculture in complementarity with additional information from TEEB case studies, other initiatives and the literature, allows identifying hot-spots where the trade-offs between water management, inland fisheries and aquaculture and sustained ecosystem services from freshwater aquatic environments, and potential for generating negative externalities, are most acute[19]:

1. **Floodplains** – where competing demands for water supporting inland fisheries and aquaculture and for rice are highest. This is the case of **Bangladesh**'s haors (e.g. Thompson and Balasinorwala 2010).

2. **Rivers and deltas** – where water allocations supporting inland and coastal fisheries and ecosystems, as well as freshwater aquaculture, compete with those for irrigation,

[19] The list of consulted maps is available in Appendix 1.

freshwater provision (drinking) and hydropower generation. This is the case for example in Egypt's deltaic ecosystems (TEEBcase 2010), and in rivers of the North America where damming conflicts with other uses such as environmental conservation and recreational fisheries (e.g. Columbia River, Leonard et al. 2015). Other areas where conflicts between fisheries and maintenance of other ecosystem services (e.g. biodiversity) and hydropower generation are acute are large rivers of Asia and in particular the **Mekong River** (Dudgeon 2000), because inland fisheries of the Mekong basin have very high direct and indirect use values (Baran et al. 2008).

3. **Large lakes and lake systems** – where fisheries (and increasingly aquaculture) conflict with biodiversity conservation, freshwater provision and agriculture in a context of increasing water scarcity, high seasonal variability and population densities. This is the case in particular in the **African great lakes**, regarding biodiversity, drinking, fisheries, aquaculture, irrigation and food security conflicts, as currently occurring in Tanzania's river basin management (TEEBcase 2011) and the well-documented Lake Victoria (e.g. Downing et al. 2014).

Out of these systems, three have been chosen for in-depth case study investigation into the valuation of fish production systems and ecosystem services and trade-offs occurring under different management and development scenarios: the Columbia River, United States; the Lower Mekong Basin, Southeast Asia, and Lake Victoria, East Africa. These three systems represent the range of aquatic ecosystems (lakes and reservoirs, rivers and floodplains), agro-climatic zones (temperate and tropical), fish production systems (large-scale, artisanal and recreational fisheries, cage and pond aquaculture), and different stakeholders (anglers, small-scale fishers and fish farmers, industrial fishers and intensive fish farmers). As is detailed in the next section, they also illustrate the wide range of ecosystem services that are derived from these systems, as well as the interdependencies and the complexity arising in their exploitation and management.

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Appendix 1: List of maps consulted to identify trade-off ‘hotspots’

To identify areas where trade-offs and externalities are potentially the greatest between fisheries, aquaculture, water use and other services (e.g. biodiversity), a number of world maps were overlaid[20]

1. Regarding water stresses and biodiversity threats:
   - Global map of incident threat to human water security and biodiversity (Vörösmarty et al. 2010).
   - Global map of physical and economic water scarcity (Molden 2007, cited in UNEP 2011).
   - Maps of Red List index (threatened species) and freshwater provision to downstream human populations (Han et al. 2014)[21].
   - Global map of freshwater withdrawals for agriculture, industrial and domestic use (WRI 2000).
   - Global maps of water risk indicators (WRI 2011).
   - Global map of coastal population and shoreline degradation (WRI 2001).
   - Global map of population densities (CIESIN 2012).
   - Global map of dams (Lehner et al. 2011)

2. Regarding fisheries and aquaculture development:
   - Global map of farmed aquatic animals for human consumption (FAO 2009)
   - Global map of the intensity of mariculture production per kilometer of coastline (Kapetsky et al. 2013) and map of fish farms in the Mediterranean Sea (Trujillo et al. 2012).
   - Global map of oceans’ health index, which includes sustainable food provision, recreation, fishing opportunities and biodiversity (Halpern et al. 2012).
   - Global maps of the human development index and inland capture fisheries and of the percentage of inland fish production from inland capture fisheries (FAO Inland Water Resources and Aquaculture Service 2003).
   - Global map of successful marine and inland fisheries co-management cases (Gutiérrez et al. 2011).

[20] The maps consulted are in different format and, for the time being, cannot be combined in a single map due to software constraints.
[21] Mapped areas focus on the Mekong, the Tropical Andes and the Great Lakes of Africa.

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is a global initiative focused on “making nature’s values visible”.
Its principal objective is to mainstream the values of biodiversity and
ecosystem services into decision-making at all levels.
It aims to achieve this goal by following a structured approach
to valuation that helps decision-makers recognize the wide range
of benefits provided by ecosystems and biodiversity,
demonstrate their values in economic terms and,
where appropriate, capture those values in decision-making.

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