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PERSPECTIVE

On the sustainability of inland fisheries: Finding a future for the forgotten

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Abstract At present, inland fisheries are not often a national or regional governance priority and as a result, inland capture fisheries are undervalued and largely overlooked. As such they are threatened in both developing and developed countries. Indeed, due to lack of reliable data, inland fisheries have never been part of any high profile global fisheries assessment and are notably absent from the Sustainable Development Goals. The general public and policy makers are largely ignorant of the plight of freshwater ecosystems and the fish they support, as well as the ecosystem services generated by inland fisheries. This ignorance is particularly salient given that the current emphasis on the food-water-energy nexus often fails to include the important role that inland fish and fisheries play in food security and supporting livelihoods in low-income food deficit countries. Developing countries in Africa and Asia produce about 11 million tonnes of inland fish annually, 90 % of the global total. The role of inland fisheries goes beyond just kilocalories; fish provide important micronutrients and essentially fatty acids. In some regions, inland recreational fisheries are important, generating much wealth and supporting livelihoods. The following three key recommendations are necessary for action if inland fisheries are to become a part of the food-water-energy discussion: invest in improved valuation and assessment methods, build better methods to effectively govern inland fisheries (requires capacity building and incentives), and develop approaches to managing waters across sectors and scales. Moreover, if inland fisheries are recognized as important to food security, livelihoods, and human well-being, they can be more easily incorporated in regional, national, and global policies and agreements on water issues. Through these approaches, inland fisheries can be better evaluated and be more fully recognized in broader water resource and aquatic ecosystem planning and decision-making frameworks, enhancing their value and sustainability for the future.

Keywords Inland fisheries · Sustainability · Governance · Integrated water resources management · Food-water-energy nexus

THE FORGOTTEN FISHERIES

Inland fisheries[1] contribute over 40 % of the world's reported finfish fisheries and aquaculture production (excluding plants, mammals, crustaceans, echinoderms, and mollusks; Lynch et al. 2016). Inland capture fisheries comprise under 10 % of this reported total but the actual fish harvest is likely substantially higher (Welcomme et al. 2010). Despite this indisputable importance, due to lack of reliable data, inland fisheries have never been part of any high profile global fisheries assessment. Moreover, the apparent low proportion of fish provided by inland capture fisheries globally does not reflect the importance of inland capture fisheries in today's society (Bartley et al. 2015). Indeed, the general public and policy makers are largely ignorant of the plight of freshwater ecosystems and the fish they support, as well as the ecosystem services generated by inland fisheries (Cooke et al. 2013; Lynch et al. 2016).

Despite mounting evidence of the immense value of inland capture fisheries for food security in the developing world (Welcomme 2011; FAO 2014), inland fisheries rarely form part of high level policy documents and fora dealing

[1] 'Inland fisheries' operate in "lakes, rivers, brooks, streams, ponds, inland canals, dams, and other land-locked (usually freshwater) waters (such as the Caspian Sea, Aral Sea, etc.)" (FAO Coordinating Working Party on Fishery Statistics: http://www.fao.org/fishery/cwp/handbook/G/en).

with food security and poverty alleviation, and are often excluded or ignored from global and regional policy discussions about water resource use and global food security (Godfray et al. 2010). As a telling example, the United Nations framework for the post-2015 development agenda (i.e., Transforming Our World: The 2030 Agenda for Sustainable Development) has a number of proposed Sustainable Development Goals (SDGs; see United Nations 2016) that replace the previous Millennium Development Goals (Sachs 2012), and inland fisheries are nowhere mentioned. Indeed, marine fisheries feature prominently in the Oceans SDG (SDG 14—Life below water), while the Terrestrial SDG (SDG 15—Life on land) references "inland freshwater ecosystems" but makes no explicit mention of fisheries despite the obvious links between inland fisheries and human health, well-being, and livelihoods.

Overlooking inland fisheries has serious consequences for the well-being of millions of people, particularly in the developing world, where inland fisheries support livelihoods for 60 million people and food for hundreds of millions more (Smith et al. 2005; The World Bank 2012). Additionally, freshwater recreational fishers globally contribute some $70 billion to the global GDP (The World Bank 2012). It is time to acknowledge the full value of inland fisheries, especially in the context of food security, human health, livelihoods, and tourism (see Lynch et al. 2016), and ensure their future sustainable management, particularly in the face of competing uses of freshwater (e.g., irrigation, hydropower, domestic and industrial use, and waste disposal). Moreover, freshwaters are subject to threats arising from extensive habitat alteration, fragmentation (i.e., dams), and invasive species, that are negatively affecting freshwater biodiversity (Bruton 1995; Dudgeon et al. 2006). In the marine realm, the threats to fisheries tend to be internal to the sector (i.e., overfishing), while in inland waters the threats are largely external (Beard et al. 2011; Cooke et al. 2014). The loss of biodiversity in freshwater is believed to exceed that observed in both terrestrial and marine environments (Ricciardi and Rasmussen 1999). Freshwater fishes are the most threatened group of vertebrates on Earth after amphibians (Bruton 1995; Sala et al. 2000), and the global extinction rate of fishes (includes marine fish) is believed to exceed that of other vertebrates (Sisk et al. 1994; Bruton 1995).

FAO recently acknowledged the crucial role of inland fisheries in food security and poverty alleviation, and recognized the need for improved information on, and sustainable development of, the sector (FAO 2014). To address the challenges for inland fisheries on a global scale, FAO, in partnership with Michigan State University, convened a cross-sectoral conference in Rome, Italy, 26–28 January 2015, entitled *Freshwater, fish, and the future—cross-sectoral approaches to sustain livelihoods, food security, and aquatic ecosystems* (http://inlandfisheries.org). National resource officers, policy makers, indigenous peoples, academics, civil society organizations, and the international development community gathered to discuss issues of economic, sociocultural, and ecological importance associated with global inland fisheries. Here, we summarize the characteristics of these fisheries and provide key policy recommendations for their sustainable development that emerged during the Global Conference on Inland Fisheries.

ABOUT INLAND FISHERIES

Inland fisheries are diverse, use multiple species (including non-fish), often geographically dispersed, and involve commercial, subsistence, recreational, and aquacultural components (reviewed in Welcomme et al. 2010; Cooke et al. In Press b). They range from small-scale subsistence fisheries to large-scale industrial fisheries, and include extensive ornamental and recreational fisheries (FAO 2010; The World Bank 2012; Cooke et al. In Press b). In many inland fisheries, aquaculture and capture fisheries are tightly linked through stock and habitat enhancement activities, mainly because aquaculture technologies are often well developed and accessible and because the small-scale and confined nature of many inland fisheries enables governance systems that are conducive to active management (Lorenzen 2014).

Developing countries, mainly in Asia and Africa, produce 90 %—about 11 million tonnes—of reported global inland capture fisheries output (FAO 2014). A large share of these landings is destined for local human consumption and bartering, while a smaller share provides high value export products (e.g., Nile perch [Thorpe and Bennett 2004], some Mekong catfishes [Belton et al. 2011]). In areas where malnourishment is a common threat, inland fisheries provide a vital source of protein, essential fatty acids, and other micronutrients not readily found in other accessible food sources (Youn et al. 2014). Replacing capture fish production with other animal-source foods would require using more land, greater energy input and higher greenhouse gas emissions, more water withdrawal, and production of more agrochemical pollution (Hall et al. 2013; Hilborn 2013). Given the natural reproductive capacity of many inland fishes and the local-level, informal trade of most inland capture fisheries (The World Bank 2012; Asche et al. 2015), well-managed inland fisheries are likely to be the most sustainably produced source of animal protein on the planet. Even sustainable aquaculture, of both herbivorous and omnivorous species, has a more efficient food conversion ratio (<2 kg of dry feed per 1 kg of gain) than poultry (2-to-1), pigs (4-to-1), and cows (7-to-1)

(Brown 2002; Troell et al. 2004). International trade of inland fisheries products is variable (Asche et al. 2015) and it is unclear if such trade always contributes to local poverty reduction and food security (Béné et al. 2010; Eggert et al. 2015).

The nutritional value of inland fisheries is magnified by their accessibility. Inland water bodies are widely distributed in many natural and man-made landscapes, and their fisheries resources are often very accessible, being neither privately owned nor technically difficult to catch. As a result, inland fisheries are often utilized as part of complex rural (farming and fishing) diversified livelihoods (e.g., combined rice and fish culture in southeast Asia; Fernando 1993; farming during wet season and fishing during dry season in the Republic of Chad; Sarch and Birkett 2000) and are available to support the poorest people in times of crisis such as catastrophic crop losses or displacement by civil war (Smith et al. 2005). This accessibility can enable over-exploitation if fisheries are not well managed. On the other hand, inland fisheries can be substantially enhanced where access restrictions are acceptable and technical means available (e.g., juvenile fish for stocking from the aquaculture industry). In many developed countries, inland fisheries provide not only food but also lucrative recreational fisheries (Arlinghaus and Cooke 2009; Cooke et al. 2015; Tufts et al. 2015) and are increasingly being recognized as sources of livelihood support in developing countries (Bower et al. 2014; Barnett et al. 2015).

Inland fish contribute to human well-being as a source of livelihood through catching, processing, and trading activities, with disproportionally more jobs for women. They also contribute to sustaining cultural identities (e.g., indigenous communities in the Pacific northwest; Kew 1992), maintaining cooperation and social cohesion among riparian people, and providing job satisfaction for millions of people (Pollnac et al. 2001), and, they provide additional ecosystem services by functioning as pest control, influencing food webs, and through nutrient transport (Holmlund and Hammer 1999; Lynch et al. 2016). These local-level contributions aggregate to bring well-being and prosperity to local, regional, and national communities in areas rich in inland fish resources (FAO 2014; Box 1). It is worth emphasizing that the aforementioned benefits can only be maintained or realized if inland fisheries are appropriately managed.

Diverse inland fish assemblages are essential to maintain ecosystem integrity and resilience, as well as the human communities that depend on these fisheries for societal well-being (Schindler et al. 2010). At the same time, inland fishes belong to the most threatened group of vertebrates on the planet (Sala et al. 2000) in part because their habitats, freshwater ecosystems, are among the most altered and threatened ecosystems in the world (Vörösmarty et al. 2010). Competition for freshwater resources by various sectors is high and continues to increase; these activities external to the fishery are the greatest threat to the viability of inland fisheries (Beard et al. 2011). Hydropower and navigation disrupt the integrity and connectivity of aquatic habitats, while agricultural practices and pollution from land-based activities can further impact the productivity of inland waters and their fisheries (Limburg et al. 2011). Aquaculture is often seen as a substitute for wild fish. However, aquaculture usually does not provide the same cultural, ecological, and nutritional goods currently provided by inland capture fisheries and may not benefit those currently engaged in capture fisheries (Roos et al. 2007). Moreover, aquaculture can be a threat to wild fish stocks (Lorenzen et al. 2012).

THE WAY FORWARD: FROM FORGOTTEN TO APPROPRIATELY VALUED, GOVERNED, AND MANAGED

We provide three key recommendations that are intended to overcome the issues highlighted above. These recommendations ensure that the status of inland fish production, as well as the economic benefits and cultural contributions of inland fisheries, is better understood and valued; that there is capacity and incentives for effective governance; and that improved valuation and governance structures promote and enable integrated water resource management at multiple scales that benefit fish and human well-being.

Invest in improved valuation and assessment

By virtue of quota/total allowable catch-based fisheries, embedded fisheries observers, landing statistics at port, tracking exports on international markets, catch reconstructions, and vigorous stock assessment programs, the regional and global status and value (especially in economic terms) of most commercial marine fisheries are well quantified (e.g., FAO 1999; Garcia and Rosenberg 2010; Pauly and Zeller 2016) notwithstanding potential to manipulate such information (Watson and Pauly 2001). Marine small-scale (e.g., Chuenpagdee et al. 2006) and recreational (Cisneros-Montemayor and Sumaila 2010) fisheries are not only more challenging to assess and value but they are also considered reasonably well characterized. This tends to be in stark contrast to inland fisheries (Welcomme et al. 2010; Cooke et al. 2014; De Graaf et al. 2015). The dispersed and small-scale nature of most inland fisheries (but see exceptions such as salmon culture industry; Asche et al. 2015) place them as generally of low economic and sociocultural priority for data collection

Box 1 A summary of selected statistics that exemplify some of the forgotten facts related to the value of inland fisheries in terms of food security and economics (including livelihoods)

The forgotten facts

The food

Over 90 % of inland fisheries production is used for human consumption (Welcomme et al. 2010)

~ 250 million children worldwide are at risk of Vitamin A deficiency, while 140 g of fish in Bangladesh supplies a child's weekly Vitamin A needs (Craviari et al. 2008)

Zinc deficiency causes 800,000 child deaths a year, while 20 grams of a small fish from the Mekong River contains the daily needs of iron and zinc for a child

Replacing fish expected to be lost from the construction of dams on the Mekong with beef would require about 40 % more land and about 40 % more water withdrawal from the river (Orr et al. 2012)

The finances

More than 60 million people in low-income countries rely upon inland fisheries as a source of livelihood (FAO 2014)

In Germany, freshwater angling is a €5,2 billion industry supplying 52,000 jobs—more than the entire non-recreational fisheries sector

The recreational fishery on the Canadian side of the Laurentian Great Lakes is valued at US$446 million per year compared to the commercial fishing sector valued at US$35 million

Freshwater species represent ~90 % of the ornamental fish trade with an estimated world export value of US$174 million and import value of US$257 million in 1998 (with average trade growing at approx. 14 % per year; FAO 2005–2015)

efforts. Inland fisheries thus lack both accurate global-level production and harvest statistics and local-level biological assessment data to inform management activities (Bartley et al. 2015; De Graaf et al. 2015).

At present, there is a lack of standard monitoring information for the hundreds, or even thousands, of independent inland fisheries stocks (Bonar and Hubert 2002), leading to the "invisible collapse" of some inland recreational fisheries (Post et al. 2002), and likely artisanal and subsistence fisheries (See Allan et al. 2005), even in developed nations. There is also evidence for "shifting baselines" in inland waters (Humphries and Winemiller 2009) which creates some level of urgency for assessing the state of global freshwater fish assemblages. The lack of capacity for biological monitoring makes sustainable management difficult given the integrated nature of the assessment-management cycle (Krueger and Decker 1999). All too often management occurs in the absence of assessment or assessment occurs and is not directly linked to the fisheries management cycle or integrated into adaptive management or an ecosystem approach framework. As such, the evidence-based approaches to management so sorely needed in inland waters (Lapointe et al. 2014; De Graaf et al. 2015) are impossible to realize. A lack of reliable information on the status of inland fisheries makes decision-making problematic and led to Bartley et al. (2015) posing a number of questions: Is the inland fisheries sector suffering from the multiple uses of and threats to inland water ecosystems? Is the sector stable with increased production over the last decade due only to better reporting? Or, is the sector actually growing?

Novel valuation and assessment approaches are needed to support broader policy development and direct more localized management actions. The most commonly quantified provisioning service of inland fisheries is the direct first-sale and market-based value of fish, which is often used in policy negotiations with other uses of freshwater ecosystems (Welcomme 2001; Béné 2009; FAO 2014). As simple as it may seem, even this service is extremely difficult to record because many inland fisheries are fragmented and subsistence in nature (i.e., many of them never involve the exchange of money). Household consumption, bartering, and trade occur through informal markets (Asche et al. 2015). Use of household surveys (typically delivered by agriculture agencies) to obtain information on household patterns of consumption is a promising approach for quantifying harvest and value of fish for food (Hortle 2009); this approach is widely used in southeast Asia (e.g., Navy and Tiongco 1998). Similarly, more directed community-based value chain studies can provide key information on informal markets. Alternative approaches to estimate global production include remote sensing techniques and estimating production by habitat type (Deines et al. 2015; De Graaf et al. 2015), use of environmental DNA, and hydroacoustic studies (reviewed in Cooke et al. In Press a).

Improved valuation of inland fisheries must be aligned with their importance to human well-being and should maintain accessibility and availability of nutrient-rich fish in areas with traditionally high fish consumption often the same regions that have higher levels of under-nourishment and malnourishment. Ensuring and promoting fish availability and consumption, particularly for children in the "first 1000 days," is important to prevent malnourishment and support cognitive development (Roos et al. 2007). Food consumption analysis is crucial at local and community levels because the dependence on fish at the local-scale is often masked in regional- or national-level data with different consumption dynamics. Better understanding of the overall nutritional contribution of inland fishes, beyond kilocalories, is essential to promote integration into effective governance strategies of freshwater management systems.

Build capacity and incentives for effective governance

Lack of ecosystem service valuation and effective multi-jurisdictional or cross-sectoral governance can only be addressed if current capacity to govern is improved. Rather than trying to strengthen the capacity of fisheries departments, sectors with higher assessment and cross-sector and cross-scale governance capacity, such as public health and nutrition, or agriculture, could be encouraged to include inland fisheries in their programming. Additionally, greater use can be made of the traditional ecological knowledge, traditional user rights, and traditional governance structures (e.g., self-organized fisher associations) that are recognized in international instruments such as the Convention on Biological Diversity, the 2007 *United Nations Declaration on the Rights of Indigenous Peoples*, and the FAO Code of Conduct for Responsible Fisheries (FAO 1995) and the FAO Voluntary Guidelines for Securing Sustainable Small-Scale Fisheries in the Context of Food Security and Poverty Eradication (FAO 2015).

Cross-jurisdictional and -sectoral coordination can address "higher order" issues that impact on fisheries, such as those that cross political boundaries and those that relate to multiple sectors, like agricultural run-off and hydropower (Biggs et al. 2014). Fostering local-level self-governance and co-management, by applying principles for sustainable institutions, will thus be of utmost importance (Ostrom 2011) and incentives should be provided for doing so (Grafton et al. 2006; Gutiérrez et al. 2011). Strategies to create incentives for resource-user communities to invest in the long-term conservation of freshwater habitats and fish

stocks fall into four main categories: (i) strengthening fishing rights, (ii) increasing participation in fishery and environmental management decision making, (iii) reducing vulnerability of fishing people to the range of pressures that may reduce their capacity and incentive to participate in environmental management and defend their fishing rights, and (iv) payments for ecosystem services that incentivize conservation (e.g., of riparian forests and floodplains).

Strengthening fishing rights—whether through defining individual or community catch shares or managing designated fishing territories—increases the incentives of resource users to manage resource for long-term sustainability as they include securing their exclusive access to resources by strengthening access and use rights (Grafton et al. 2006; Gutiérrez et al. 2011). Similarly, involving fisherfolk in decision making over both fisheries management and wider environmental management gives them a voice in management and policy (Evans et al. 2011). There are a number of emerging examples of effective co-management of inland fisheries around the globe that can be used as models (e.g., Cambodia, Ahmed et al. 2006; East African inland fisheries, Nunan et al. 2015). Although governance challenges can impede the implementation of co-management (Njaya 2007), a number of best practices have been identified that can help guide the process (Gawler 2002; Andrew et al. 2007).

Securing fishing rights works best where access to resources is the major source in insecurity in people's lives. However, many small-scale fishers in the inland waters of developing countries live precarious lives as marginalized ethnic minorities and landless poor people. They may live in remote areas poorly served by health, education, and social protection programs or amid civil and regional armed conflict. They may thus face a multitude of risks unrelated to the health of fish stocks (Mills et al. 2011). In these circumstances, attention to this broader rights and vulnerability context is also required to incentivize and capacitate resource stewardship. This can take the form of a variety of social sector and livelihood investments, according to local needs (Allison et al. 2011a, b).

Finally, where there are opportunities to do so, payments for ecosystem services (PES), such as for maintenance of riparian forest, or payments to manage floodplain land in ways compatible with fish and wildlife conservation could be explored. Such strategies are being piloted in the conservation of the culturally valued Hilsa fish in Bangladesh (Wahab et al. 2014). The capacity to integrate values of ecosystems services across sectors into decision making about inland waters is necessary to ensure that valuation efforts are directly linked to policy opportunities and outcomes (Cowx and Portocarrero Aya 2011).

Manage inland waters across sectors and scales

The institutional framework of most national and international entities does not effectively address cross-sectoral issues relating to freshwater use and integrated management (i.e., responsibilities for agriculture, water management, nature conservation, and inland fisheries are often separated over multiple agencies) (Cowx 1998). Although this perspective article is primarily about inland fisheries, we recognize that inland fisheries are simply one component to the full system. There is a need for thinking in the context of integrated water resources management. Integrated water resource management is often regarded as a necessity where biophysical and socio-economic elements are integrated (Newson et al. 2004) but there can be challenges with operationalizing it on scales that are meaningful and effective (Suhardiman et al. 2012). Additionally, discussion is needed on the type of political, economic, and social management organization required to create a space where human well-being and ecological integrity are maintained along with other water use priorities (Clausen and York 2008). Aligning water resource management policy with the sustainable livelihoods approach to fisheries development within a co-management framework (See Allison and Horemans 2006) would ensure that the value of inland fisheries is realized and that societal interests are addressed (Turton et al. 2007).

Existing organizations, decision-making frameworks, and formal and informal institutions need to be restructured or new ones need to be created to provide a forum for the integration of the numerous freshwater stakeholders, including traditional fishers, indigenous peoples, and women, as part of an integrated systems approach (Liu et al. 2015). Such efforts would best be framed around natural boundaries such as watersheds and explicitly include humans as part of coupled socio-ecological systems (Collares-Pereira and Cowx 2004). Lake Victoria and Lake Michigan exemplify cross-sectoral and scale issues in developing countries and a developed country, respectively. Lake Victoria is Africa's most important inland fishery, providing income for 2 million and food for 22 million in the region (Lake Victoria Fisheries Organization 2016). It is an open access fishery co-managed by three countries through the Lake Victoria Fisheries Organization (Van der Knaap et al. 2002) where pressure on the non-native species has led to a resurgence of native species (Balirwa et al. 2003). Although some fish products are used locally, there are also international exports which may not contribute to local food insecurity or poverty reduction (Eggert et al. 2015). Lake Michigan supports a highly valuable recreational fishery with over 400 000 anglers annually (U.S. Department of the Interior et al. 2011). Also targeting non-native species, this fishery is managed by two

state governments and tribal governments with facilitation from the Great Lakes Fishery Commission (See Karkkainen 2006). Transboundary management is complex; development of tools and approaches that incentivize collaboration across water use sectors and jurisdictions is necessary to insure sustainable management of all the services produced by these systems (Loucks 2000).

CONCLUSIONS

At present, inland fisheries are not often a national or regional governance priority; they are undervalued, largely overlooked, and often threatened in both developing and developed countries. At the same time, well-managed inland fisheries support highly sustainable and provide locally available food and outlets for the continued interactions of society with nature. Given the proposed changes to the world's most productive inland fisheries system, such as the Mekong River (Orr et al. 2012) and other large watersheds (Winemiller et al. 2016), and the unknown impacts that modifications to the system will have on the food security in the region, increased awareness of the importance of inland fisheries is necessary. A key first step could be the recognition of inland fisheries and the outputs of the Global Conference as priorities at FAO's 32nd meeting of the Committee of Fisheries in June 2016 and other international fora, such as UN Water. If inland fisheries are recognized as important to food security, livelihoods, and human well-being (see Fig. 1), creating linkages between inland fish and fisheries into the post-2015 SDGs that relate to water issues will be easier.

It is our hope that the discussion of inland fisheries will be more easily incorporated into future decisions about use

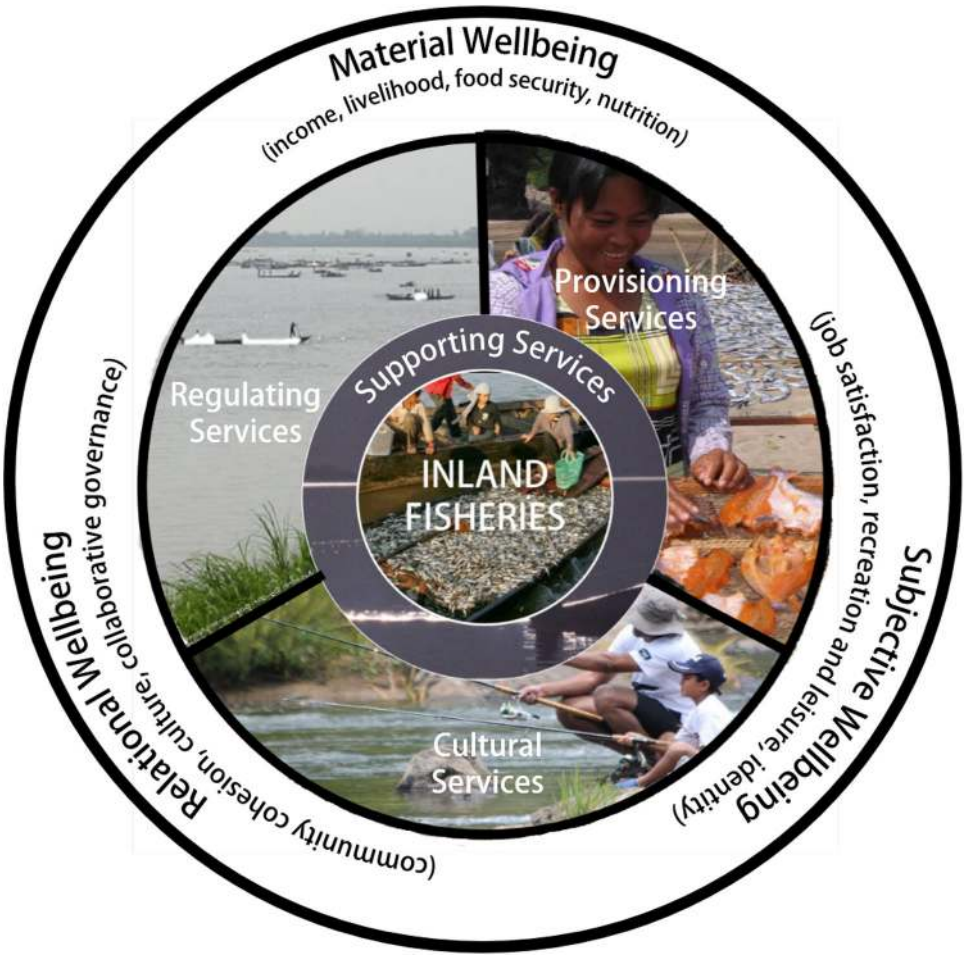

Fig. 1 The relationship between inland fisheries, ecosystem services (Millennium Ecosystem Assessment 2005), and the three dimensions (subjective, material, and relational) of the human well-being framework (Weeratunge et al. 2014). Ecosystem services provided by inland fisheries support material well-being such as practical welfare and standards of living (e.g., food, nutritional, and economic security, poverty alleviation); relational well-being including personal and social relations (e.g., community building, social security and cohesion, social capital, mutual respect) and subjective well-being such as concerns, values, perceptions, and experience of an individual (e.g., sense of identity, traditions, livelihood, culture, and hope)

of the world's inland systems. At some level, inland fisheries are related to nearly all of the SDGs and sustainable management of inland fisheries could be an effective method for countries with inland fisheries to advance on multiple SDGS simultaneously. In that context, the SDGs could provide the integrative, holistic framework needed for the sustainable management of inland fisheries. These recommendations are timely given the FAO Blue Growth Initiative,[2] which recognizes the value of fish to livelihoods and food security (see Dugan et al. 2010). Through these approaches, inland fisheries can be better evaluated and be more fully recognized in broader water resource and aquatic ecosystem planning and decision-making frameworks, enhancing their value and sustainability for the future. Although inland fisheries have traditionally been forgotten (relative to marine fisheries; see Cooke et al. 2014), we see a future where there is the political will and public desire to properly assess and manage inland fisheries in an integrated water resources management framework to benefit society while balancing needs for conservation of biodiversity.

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