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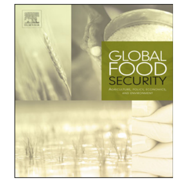

Inland capture fishery contributions to global food security and threats to their future

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ABSTRACT

Inland fish and fisheries play important roles in ensuring global food security. They provide a crucial source of animal protein and essential micronutrients for local communities, especially in the developing world. Data concerning fisheries production and consumption of freshwater fish are generally inadequately assessed, often leading decision makers to undervalue their importance. Modification of inland waterways for alternative uses of freshwater (particularly dams for hydropower and water diversions for human use) negatively impacts the productivity of inland fisheries for food security at local and regional levels. This paper highlights the importance of inland fisheries to global food security, the challenges they face due to competing demands for freshwater, and possible solutions.

1. Introduction

Food security occurs "when all people at all times have access to sufficient, safe, nutritious food to maintain a healthy and active life" (World Health Organization, 2014). Thus, in order for a community to be food secure, people must have access both to an adequate supply (amount) of food as well as receive adequate nutrients from their food. The contribution of different food products to global food security primarily focuses on agriculture and aquaculture (Rosegrant and Cline, 2003). Unfortunately, these assessments often fail to account for the contribution of fisheries, particularly wild inland (freshwater) fisheries, to food security. Inland fisheries (fish harvested from freshwater) are globally distributed and have been reported to be a rich source of nutrients, such as protein and calcium, that are crucial to human health (Belton and Thilsted, 2014). In many communities inland fish are the primary animal protein source and a vital component in ensuring food and nutritional security at the local and regional levels, especially in developing countries.

This paper addresses wild capture fisheries in inland waters and does not specifically consider aquaculture. The Food and Agriculture Organization of the United Nations (FAO) defines aquaculture to be "the farming of aquatic organisms in inland and coastal areas, involving intervention in the rearing process to enhance production and the individual or corporate ownership of the stock being cultivated" (Crespi and Coche, 2008). Although aquaculture is a growing segment of fisheries, we view it as a competing sector that impacts wild inland fish production in terms of freshwater use and fish habitat. We acknowledge that often the distinction between culture and capture is not absolute. For instance, there are capture fisheries for early life-history stages in open access fisheries that are then grown out by the 'owners' of the fish and sold (Lovatelli and Holthus, 2008). Similarly, many open-access water-bodies are stocked with larvae or juveniles raised in hatcheries (Welcomme and Bartley, 1998), thus creating culture-based "wild" fisheries. The focus of this review is on wild fish production in non-confined aquatic ecosystems whose production is determined solely by the ecological processes of the aquatic environment (e.g. lakes and rivers).

Currently, due to inadequate assessment and, as a result, poor data availability, the importance of inland fisheries to global food security is likely portrayed as being much less than what it truly is (Miao et al., 2010), often leading decision makers to undervalue

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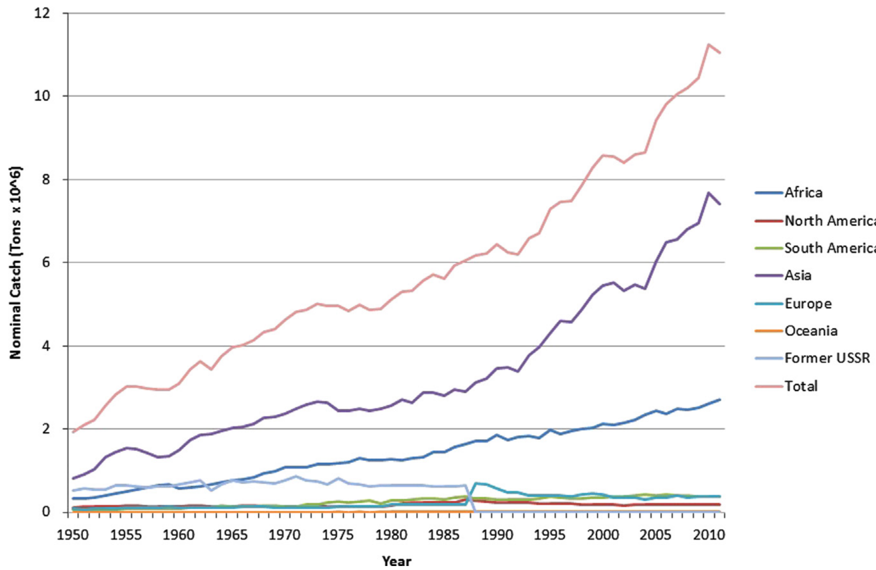

Fig. 1. Global and regional production of inland fisheries (FAO, 2014).

the importance of inland fisheries, particularly as a source of food security (Béné and Neiland, 2003). The goal of this paper is to highlight the importance of inland fisheries to global food security, outline the threats they face, and raise awareness of the benefits provided by wild capture inland fisheries.

2. Use and production of inland fisheries

2.1. Production of inland fisheries

Globally, only 156 of over 230 countries and territories reported inland capture fisheries production to FAO in 2010 (FAO, 2014). These data indicate that there has been an increase (about 6 fold since 1950) in the reported contribution of wild-capture inland fisheries to global food supply (Fig. 1).

Based on harvest numbers reported to FAO, inland fisheries production comes predominately from Africa and Asia (Fig. 1). Seventy-one Low-Income Food-Deficit Countries produce 80% – nearly 7 million tons – of the reported global inland capture fisheries output (FAO, 2012). Of the recorded harvested species, the most frequently harvested taxa in capture fisheries are cyprinids (family *Cyprinidae*) and tilapias (*Sarotherodon*, *Oreochromis*, and *Tilapia* spp.) (FAO, 2014).

The reported general expansion of inland capture fisheries could be, in part, a reflection of improved reporting in the major production areas of Asia and Africa rather than an actual increase in harvest (FAO, 2012). The high levels of inland fisheries production now recorded, and their contribution to local food security, have probably existed for some time (Welcomme et al., 2010), however, the lack of reliable data over time makes it difficult to discern trends in inland fisheries production. Although reported statistics seem to indicate production is increasing, actual production may be decreasing as inland fish populations are affected by overexploitation and habitat loss (Raby et al., 2011).

2.2. Problems with data concerning inland fisheries production

Inland fisheries production data is generally inaccurate and under-reported (Béné and Neiland, 2003; Jesús and Kohler, 2004; Welcomme, 2011). In the Ayeyarwaddy Division of Burma (Myanmar) for example, official statistics report inland production for 1999–2000 as 90,813 MT while household consumption studies suggest production is closer to 235,760 MT (Coates, 2002). Likewise, Hortle et al. (2008) found that in Cambodian rice paddies, direct monitoring of fish yield for one season (119 kg/ha/year) resulted in estimates that greatly exceeded previously reported yield estimates (25–62 kg/ha/year).

Obtaining more accurate information about inland fisheries production is inherently a difficult process because most inland fisheries activity is small-scale in nature, highly dispersed, and generally unreported to governmental agencies (Allan et al., 2005). In many artisanal and recreational fisheries throughout the world, there are no direct estimates of fish harvest as many of the fish captured in these areas are consumed directly or sold/bartered through local, informal markets (Bennett and Thorpe, 2006; Ronnback, 1999). As a result, even though these fishes are playing an important role in enhancing local food security, their importance is not being accurately reflected in the production values that are reported and thus are often invisible in policies and decisions regarding food security and water use.

Procedures that account for the unreported and unrecorded fish, in addition to traditional catch assessment methods (recording of catches at landing sites), are needed in order to provide a more complete representation of the benefits of inland fisheries. Doing so requires routine targeted surveys of household dynamics and food consumption studies, biological assessment related to environmental characteristics that effect fish production using both direct census methods and remote tools, intensification of catch assessment methodologies, and using local communities to support data collection and reporting (Beard et al., 2011; Bonar and Hubert, 2002). Large scale monitoring of inland fish harvest/yield data in most of the world is unrealistic given the cost associated with implementation given its highly dispersed nature among the world's many water bodies. However, other approaches to estimating fish yield may have the potential to produce better estimates than are currently generated officially by governments. For instance, numerous studies have shown a relationship between fisheries productivity and measures of primary production (Janjua et al., 2008; Ssanyu and Schagerl, 2010). Given the relationship between measures of primary production and fish productivity, at least for larger bodies of water, remote sensing based approaches to estimating measures of primary production (Brezonik et al., 2005) may offer a low-cost alternative to collecting data on potential fish yields. Although remote based approaches only allow an estimation of potential fish harvest, proper coupling with periodic on the ground monitoring techniques may allow for development of relationships between potential and actual harvest in inland waters.

Another approach to estimating fisheries yield that has been tried in numerous fisheries (mainly Southeast Asia) are consumption based approaches for estimating fisheries production (Welcomme, 2011). Consumption based approaches could be useful in countries where most of the fish harvest is reduced to personal possession and consumed within the household and can generally be found as part of overall nutrition surveys within individual countries (Kearney, 2010). Where consumption approaches have been used (Dey et al., 2008) estimates of total harvest from consumption approaches almost always exceeds officially reported harvest statistics. Consumption studies may be regarded as a more accurate measure of wild inland fish production, at least on a local level (Hortle, 2007). Large scale integration of consumption based estimates of fish into national approaches to estimating nutritional demands provides hope for generating better estimates of total inland fish production.

In 2011, FAO estimated total inland fisheries harvest in excess of 11 million tons, which had an estimated first sale value of US $5.5 billion (FAO, 2012). According to Welcomme (2011), inland fish production could rival marine (saltwater) fish production (83.72167 MT (FAO, 2012)) when all bodies of freshwater globally (e.g. small streams, ponds, lakes, and rivers which are currently not assessed) are accounted for (Fig. 2).

2.3. Use of inland fisheries

Exploitation of inland fisheries ranges from family-based artisanal units operating in small ponds to commercial enterprises with motorised boats fishing in larger lakes and rivers. Although commercially intensive fisheries for food exist in inland waters (e.g. lake whitefish *Coregonus clupeaformis* in the Laurentian Great Lakes (North America) (Ebener et al., 2008), Nile perch *Lates niloticus* in Lake Victoria (East Africa) (Geheb et al., 2008), piraiba catfish *Brachyplatystoma filamentosum* in the Amazon River (Petrere et al., 2005)), inland fisheries are generally characterised by small-scale, household-based, and subsistence fishing in which the majority of the catch is consumed locally rather than being exported to other locations. In the Congo, for example, 60% of the fish caught by women are consumed by their household and the rest is bartered for other goods (Béné et al., 2009). There is generally little "bycatch" (fish caught incidentally with target species and discarded) as practically all fish caught are consumed (Raby et al., 2011; Welcomme, 2001). Due to its largely subsistence nature, participation of individuals in local inland fisheries is consequently very high, especially in rural areas of developing countries.

In addition to being a direct source of food security (by producing fish), inland fisheries are also an important source of livelihoods and economic security, which indirectly increases food security by providing people with the economic means (income) of securing food in the marketplace. Inland fisheries provide livelihoods to fishers (direct employment) and others involved in the fisheries industry (indirect employment, e.g. selling, processing). A report in 2009 estimated that more than 56 million people were directly involved in inland fisheries production in the developing world (BNP, 2009), 54% of which were women (mostly involved in processing and selling) (Welcomme et al., 2010). In West and Central Africa, a study of 7 river basins found that fisheries in these areas supported 227,000 full-time fishermen and had a first-sale value of $295.17 million (Neiland and Béné, 2006). In Southeast Asia, more than 50% of jobs in inland fisheries are held by women (Dugan et al., 2010). In Sub-Saharan Africa, women also hold jobs in inland fisheries, giving them additional income to provide nutrition for their children (Heck et al., 2007). Fisheries can also be an important, steady livelihood for female-headed households, especially as other livelihood options tend to be scarce (Kyaw, 2009). The livelihoods provided by inland fisheries provide income for households to obtain food and other products, either through purchase or barter. Consequently, inland fisheries contribute both directly and indirectly to local health, wellbeing, quality of life, and overall food security.

3. Nutritional value of inland fish

Fish are an important source of animal protein and micronutrients. In much of the developing world, inland fish, particularly small native fishes, are the main source of animal protein as other types of animal protein are either not as readily available or are cost-prohibitive and consequently are rarely consumed (Bell et al., 2009; Dugan et al., 2006; Hall et al., 2013; Jamu et al., 2011). Fish are also a key source of vital micronutrients (elements required in trace amounts for normal growth and development), such as calcium, vitamin A, iron, and zinc (Kawarazuka and Béné, 2011; Mazumder et al., 2008) (Table 1).

In the developing world the majority of inland fish that are consumed are small and eaten whole, fermented, or ground into a paste (including the bones), providing a major source of calcium (Hansen et al., 1998; Kawarazuka, 2010). This, combined with consumption of fish rich in vitamin D (such as rainbow trout

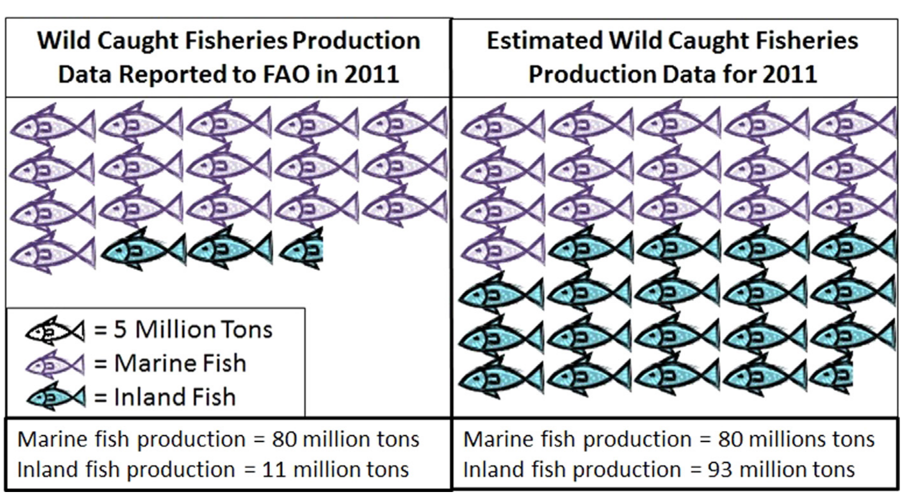

Fig. 2. Graphical depiction of reported (FAO, 2012) and potential (Welcomme, 2011) global fish production for marine and freshwater fisheries.

Table 1
Nutrients present in freshwater fish and their importance to human health.

Nutrient from freshwater fish	Importance to human health	Citation
Protein	Source of amino acids Growth Muscle mass	Delgado and McKenna (1997)
Omega 3 fatty acids	Brain development	Moths et al. (2013) Guler et al. (2008)
Vitamin D	Cardiovascular health	Ostermeyer and Schmidt (2006) Lu et al. (2007)
Calcium	Bones	Roos et al. (2007a, 2007b) Chan et al. (1999)
B vitamins	Energy production	Steffens (2006)
Vitamin A	Vision Tissue growth	Roos et al. (2007a, 2007b)
Iron	Formation of hemoglobin and myoglobin Component of many proteins	Steiner-Asiedu et al. 1991 Lazos et al. 1989
Zinc	Cellular metabolism	Gibson et al. (1998)
Lysine	Amino acid	Adeyeye (2009)

Oncorhynchus mykiss and perch *Perca fluviatilis* (Mattila et al., 1999) and cyprinid species), contributes to improved bone health and neuromuscular function since vitamin D is necessary for successful absorption of calcium by the human body (Pettifor, 2004). Fish also contain important B vitamins and trace minerals, such as selenium (which is important for proper immune function (Rayman, 2000)), that are beneficial to human health.

In addition to protein and micronutrients, inland fish are an important source of the omega-3 fatty acids eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA). Fish provide omega-3 fatty acids in greater quantity and in a more biologically usable form (EPA rather than LNA) than do plant sources of omega-3s (Nettleton, 1991). While marine fish tend to have higher levels of omega-3 fatty acids than freshwater fish (Abouel-Yazeed, 2013), some freshwater species (e.g. rainbow trout (*O. mykiss*), Siscowet lake trout *Salvelinus namaycush siscowet*), common carp (*Cyprinus carpio*), wild tilapia (*Oreochromis*, *Tilapia* spp.), highwaterman catfish (*Hypophthalmus edentatus*), and speckled pavon (*Cichla temensis*)) can contain high amounts of EPA and DHA (Gogus and Smith, 2010; Guler et al., 2008; Inhamuns and Franco, 2008; Steffens and Wirth, 2005; Wang et al., 1990; Young, 2009). EPA and DHA have been associated with a variety of health benefits (e.g. maintenance and growth of normal brain function) and the reduction of several human diseases (e.g. Alzheimer's disease, cardiovascular disease, arthritis) (He et al., 2004; Horrocks and Yeo, 1999). Higher levels of these acids in red blood cells have been associated with larger total brain and hippocampal volumes, which are associated with better brain function (Pottala et al., 2014). Due to the many health benefits of omega-3 fatty acids, freshwater fish with high omega-3 fatty acid content are an important component of human diets, particularly in areas where other sources of EPA and DHA are difficult to obtain.

Additionally, the nutrients found in fish, especially calcium and omega-3 fatty acids, are important for pregnant and lactating women in order to ensure healthy development of young children. Adequate consumption of these nutrients is important to ensure that these nutrients are being passed on to their children in sufficient amounts so that children (particularly infants) have the nutrients they need for healthy growth (Daniels et al., 2004). In Tanzania, for example, women with high consumption of freshwater fish had DHA levels in their breast milk that were above the recommended levels for commercial baby formulas (Kawarazuka, 2010). Loss of these inland fish species would thus remove a significant source of essential micronutrients from the diets of these populations. Replacing these species with other fish species may not provide the same nutrients (since different fish provide different nutrients and in different quantities) and may not be as accessible to the populations that depended on the original inland fish species (either due to price or availability) (Belton et al., 2014).

Nutrition is important, not only for proper growth and development, but also for prevention of illness. In Zambia, intake of kapenta (*Limnothrissa miodon*), a small freshwater fish, has had positive impacts on reducing opportunistic infections and chronic wound healing in people living with HIV/AIDS (Kaunda et al., 2008). In parts of Bangladesh and Sub-Saharan Africa, adequate calcium intake, from freshwater fish and other sources, have been shown to prevent the development of rickets in children (Craviari et al., 2008).

4. Threats to inland capture fisheries

Underestimation of the importance of inland fisheries, particularly to food security, has led to these fisheries being seen as less of a priority (lower value) compared to other services that freshwater can provide, such as hydropower, municipal use, and irrigation for agriculture. As a consequence, inland fisheries are often poorly integrated or largely ignored in both national and local decision-making processes related to water development (Dugan et al., 2006; Sneddon and Fox, 2007). While alternative uses of freshwater have their own essential benefits, careful consideration must be given as to who is benefitting and who is suffering from policies promoting one use of freshwater over another. Aquaculture, for example, can help relieve food insecurity in a region, but farmed fish or other alternative sources of animal protein may not be substitutable (in terms of nutrient content or taste) for the native fish species. Wild tilapia, for example, tend to have a more favorable omega-3 fatty acid content than farmed tilapia (Young, 2009). Because inland fisheries have large nutritional and economic impacts on local communities, particularly in the developing world, use of local water for purposes that diminish the productivity of wild capture fisheries can have negative impacts on community nutrition and livelihoods, especially in rural areas (Kawarazuka and Béné, 2011).

One of the greatest threats to wild fish populations and fisheries productivity is changes to their aquatic habitats through anthropogenic means, coupled with over exploitation by an ever increasing human population and advancements in fishing technologies (Taylor et al., 2011, 2007). The alteration of the water (channelization, dam construction) and landscape (urbanization, agriculture and forestry practices) to provide for societal benefits such as food, housing, transportation and power generation all have significant direct and indirect influences on the productive base for fish. Changes in the water dynamics of flow and connectivity destroys native fish production and thus harvest, while changes in the landscapes affect the quantity and quality of surface and groundwater flows via increased rates of sedimentation, nutrients and contaminants, changes in temperature, and direct removal of water from water bodies to serve human needs in the watershed (Naiman et al., 1995). All these changes ultimately affect the productive base for inland fisheries and the allowable harvest of fish populations for sustainable use (Hayes et al., 1996) which generally means that exploitation must be reduced as fish habitat is lost and fish production is limited. Therefore, in concert with allowing for appropriate exploitation rates, maintaining and enhancing habitat equates to healthy and productive fish populations and fisheries.

Water development projects, such as diversion or damming of water for hydropower, agriculture and municipal use, are competing demands for freshwater that generally degrade fish habitat and can lead to lower abundance and productivity of existing fish species or extinction of some fish populations altogether (Ziv et al., 2012). While these water development projects can have some positive consequences (e.g. reservoir fisheries, such as the Lake Nassar fishery in Egypt (Witte et al., 2009)), they also change the hydrology of the water (warmer water temperatures, slower moving water leading to lower dissolved oxygen content), which can further degrade habitat suitability for other fish species (Hayes et al., 1996). Overall, these projects often reduce fish abundance, productivity, and diversity, which is detrimental to the human populations that rely on those fish for food. Small native fish species, in particular, are heavily affected (Mazumder and Lorenzen, 1999). Since small fishes are the primary source of animal protein and micronutrients for many parts of the developing world (Hall et al., 2013), scarcity of these fishes forced people to either lose this valuable nutrition source or switch to consumption of more expensive farmed species, such as carp (family *Cyprinidae*) (Kawarazuka, 2010). In doing so, people shift from consumption of multiple fish species, which is advantageous since different fish species have different nutritional contents, to reliance on a reduced diversity of fish species, which may reduce the overall quantity and diversity of nutrients being consumed (Minkin, 2013).

In addition to facing reduced food availability, local communities usually do not receive the benefits that come from water development projects. In the case of hydropower, for example, most of the electricity that is generated is sold to other countries rather than powering local communities (Burma Rivers Network, 2009; Fearnside, 1999; Grumbine and Xu, 2011). As a result, local communities are not receiving many benefits from these water development projects, but have been forced to bear the costs, especially in the loss of fish (and other species) that they depend on for food security.

Aquaculture is another alternative use of freshwater. Aquaculture development is often promoted to mitigate real or perceived declines in inland fisheries and to provide an extra source of food (Welcomme et al., 2010). Since 1980, production from aquaculture has increased dramatically (about nine-fold) (FAO, 2014). Despite its benefits, increased aquaculture may not mitigate harvest and food security losses from reduced inland capture fisheries (Kawarazuka, 2010). Aquaculture often requires inputs, such as seed (juvenile) fish and private rights to land or an area of water, that often require a substantial amount of start-up capital and consequently are not attainable by poorer segments of society (Hishamunda, 2007; Lewis, 1997; Sheriff et al., 2008). As such, at a local level, small-holder farmers and subsistence fishermen may not gain comparable food and economic benefits from aquaculture as they do from capture fisheries (Allison, 2011).

Additionally, farmed species sometimes do not provide the same nutrients as wild species (Roos et al., 2007a, 2007b; Thilsted et al., 1997). For example, a study comparing farmed, hybrid, and native climbing perch (*Anabas testudineus*) and pangas species (*Pangasius pangasius*, *Pangasius hypothalmus*) found that wild fish were more nutritious (higher protein and trace mineral content, lower heavy mineral contamination) than farmed fish, even within the same species (Monalisa et al., 2013). Thus, switching to consumption of farmed fish may deprive local communities of key nutrients that they are unable to obtain easily from other local food sources. Therefore, while aquaculture has the potential to improve food security in a region, not all fish species are equally substitutable (e.g. carp are a good source of omega-3 fatty acids but not calcium, which are more easily obtained from smaller fish species) and careful consideration must be given as to what species are being farmed and who (both within and outside the local community) is receiving the benefits (economic and otherwise) from aquaculture developments in the area (Beveridge et al., 2013).

In Bangladesh, the switch from small native species to larger farmed species, due to loss of native fish habitat and development of aquaculture infrastructure, exacerbated the incidence of rickets in young children in Chakaria (southeastern Bangladesh) (Minkin, 2013). Rickets, which was previously unheard of in Chakaria (Fischer et al., 1999), occurs when children have insufficient or impaired metabolism of vitamin D, phosphorus, and/or calcium, thus preventing their bones from solidifying (Craviari et al., 2008). A study by Kabir et al. (2004) found that while 0.9% of children had “confirmed rickets”, 16.4% of children had features suggestive of rickets. Although rickets is usually associated with vitamin D deficiency, children in Chakaria were developing rickets due to a lack of calcium (Combs and Hassan, 2005). In this region, bones of small native fish species (which were ground up or eaten whole) were the main calcium source. Development projects by the World Bank and other agencies, such as conversion of wetlands into agricultural land and large-scale hydropower, flood control and irrigation projects, had destroyed much of the native fish habitat, making the once abundant native fish species extremely scarce (Hickley et al., 2004; Mazumder and Lorenzen, 1999; McCartney, 2009). As the native fish became scarcer and more expensive, local people switched to consumption of farmed carp species, which were cheaper due to being farmed in large quantities (Minkin, 2013). Because the carp are bigger, however, the bones were more difficult to eat (grind or chew) and it was easier to separate and discard the bones from the meat. Thus bones were generally not consumed, leading to the loss of the main source of dietary calcium (Combs and Hassan, 2005). As a result, switching from small native species to the larger, farmed species deprived individuals of their main source of calcium and led to local nutritional insecurity in the formed of increased incidence of rickets in the region.

5. Ways forward

Inland capture fisheries, which can range from individual subsistence fishers to large-scale commercial operations, are an important source of food security, particularly at the local level. In developing countries, in addition to providing animal protein, inland fish are often the cheapest and most available source of vital micronutrients, particularly calcium. Despite these important contributions, inland fish and fisheries generally remain economically and socially undervalued and biologically underappreciated because accurate information about these small-scale, highly dispersed fisheries is inherently difficult to acquire. Consequently, inland fisheries are often invisible or at best given low priority in policy discussions relative to other uses of water (e.g. hydropower, aquaculture, irrigation, and flood control), which generally reduces native fish habitat availability and thus, inland fisheries production, thereby impacting local communities' food security, health, and wellbeing.

What can be done to better integrate inland fisheries into development planning and policy processes? Inland fisheries need to be made visible. They need improved assessment frameworks, value estimation, and communication with the other users of freshwater resources. Collaboration with these other sectors can lead to more socially, economically, and ecologically appropriate water allocations, including maintaining production of wild inland fish. Doing so will allow for optimization of the world's freshwater resources while maintaining the food security needs of local communities throughout the world.

For a place in policy and planning discussions, inland fisheries must be viewed as valuable to nutrition and food security using ways that can be reliably assessed and communicated. This underscores the need for reliable and timely information on fishing effort, production from inland capture fisheries, and inland fisheries consumption. Because of the small-scale, dispersed, and diverse nature of these fisheries, alternative approaches to collecting production data and monitoring inland fisheries, such as geospatial and remote sensing tools and household surveys of fish consumption, will be necessary. To ensure that inland fisheries do not stay invisible in future decision making, they must be seen as a sustainable and integral source of food security. This can only be done if the role of inland fisheries is reliably assessed and valued properly. Doing so will make this vital natural resource prominent in the food security value chain and a key element of water policy and decisions.

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