THE IMPORTANCE OF INLAND CAPTURE FISHERIES TO GLOBAL FOOD SECURITY

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ABSTRACT

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Inland (freshwater) fisheries are an important source of global food security. The contributions of inland fish to human health and wellbeing tend to be undervalued by policymakers, however, due in part to inadequate and incomplete data regarding inland fisheries consumption, harvest, and production. This thesis reviewed existing literature to 1) determine the contributions of inland capture fisheries to local and global food security and 2) evaluate the viability of using household dynamics and consumption information to estimate inland fisheries harvest and production through examination of historical case studies. The thesis examined the utility of household dynamics methods to previously collected data on recreational urban fishing in Lansing, Michigan on the Grand River in order to estimate local inland fish consumption and harvest in this region. Based on these studies, inland fisheries were determined to be an important food and nutrition source, especially to economically vulnerable households in the developing world. Additionally, the use of household dynamics and consumption studies were determined to be able to provide a useful estimate of inland fish consumption, which can be used to estimate minimum harvest for specific regions.

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INTRODUCTION

I. Food, nutrition, and livelihood benefits of inland freshwater capture fisheries

Inland fisheries (e.g. fisheries that occur in freshwater) are an important source of global food security (Belton and Thilsted, 2014), defined by the World Health Organization (WHO; 2014) as “having access at all times to sufficient, safe, and nutritious food in order to maintain a healthy and active life”. In the developing world, inland fisheries are the primary source of animal protein (Belton and Thilsted, 2014). Depending on how they are prepared and consumed, they can provide calcium, vitamin A, iron, and other critical nutrients (Kawarazuka and Béné, 2011; Mazumder et al., 2008). Oftentimes, freshwater fish are the most accessible source of these nutrients because other animal protein and nutrient sources are either too expensive (price of farmed animals is generally higher than price of locally caught fish species) or not readily available (certain areas may not support farmed animals, poorer households may not have the ability to raise livestock) (Belton et al., 2014). Additionally, in some areas (e.g. Burma), there is a cultural preference toward consumption of freshwater fish rather than marine fish (FAO, 2003).

In addition to food security, inland fisheries are also an important source of livelihoods and economic security (Béné et al., 2003). This importance can be difficult to measure, however, due to lack of information. One initiative to close this information gap is the Big Numbers Project, a joint Food and Agriculture Organization of the United Nations (FAO) and WorldFish Center project to provide information on the contribution of small-scale fisheries to food security and livelihoods (FAO and WorldFish Center, 2008). A Big Numbers Project report (2009) estimated that more than 56 million people in the developing world, 54% of whom were women (Welcomme et al., 2010), were directly involved in inland fisheries production. Due to their relatively low start-up costs, inland capture fisheries can be appealing to economically vulnerable groups, such as female heads-of-households (Welcomme et al., 2010). In many areas (e.g. Africa and Southeast Asia), women harvest fish, either for subsistence consumption or income, which serves as an additional source of food and income for their families. Additionally, women have been observed to occupy many of the fish processing and selling jobs in these areas (Béné and Heck, 2005; Chong et al., 2003).

II. Threats to inland capture fisheries

Like other natural resources, inland fisheries face many threats, which contribute to the deterioration of fish habitat and lowers fisheries productivity. Some of these threats, such as climate change, are long-term and directly or indirectly affect fisheries productivity (Timmers, 2012). Other threats, such as land- (e.g. agriculture) and water-scape changes (e.g. dams), can be long or short term, directly degrade inland fish habitat, and lower inland fisheries productivity (Mirza and Ericksen, 1996). Reduced fisheries productivity in turn reduces the amount of fish available for the people who are dependent on inland capture fisheries for food, nutrition, and livelihoods (Ziv et al., 2012).

Climate change leads to disruptions in the timing and availability of water flow (Eastham et al., 2008), which negatively impacts fish growth and survival, particularly for migratory fish (e.g. cyprinid *Probarbus jullieni;* Poulsen et al., 2002) whose migration patterns are tied to water conditions and flow (Dugan et al., 2010; Kang et al., 2009). Land-waterscapes and their alteration for human use, such as construction of dams for hydropower and diversion of water for irrigation or flood control, reduce the quality and quantity of habitat available for riverine fish (Barlow et al., 2008; Hayes et al., 1996). Climate change and landscape changes also impact the availability of freshwater, a limited and increasingly valuable resource, increasing demand for freshwater from many different sectors, including inland fisheries (Eastham et al., 2008; Li and He, 2008).

III. Lack of data on inland capture fisheries

Despite their importance to global food and economic security, inland capture fisheries are often undervalued in policy decisions, particularly in regards to freshwater allocation and use (Beard et al., 2011; Béné and Neiland, 2003). Part of this undervaluation may be due to the lack of accurate data on inland capture fisheries production and utilization (FAO and WorldFish Center, 2008). The most available source of global inland capture fisheries production is the FAO FishStat database (FAO, 2014a), which is based on self-reported production statistics from member nations (FAO, 2014b). These data, however, may be unreliable due to lack of infrastructure (e.g. no organization to measure and record fisheries data), capability (e.g. not enough fisheries officers, poorly trained fisheries officers), or resources (time or money) to accurately assess inland capture fisheries harvest on a yearly basis (FAO Fishery Resources Division, 2003). In some areas, inland fisheries data may be unavailable or poor quality due to the perceived lack of importance of inland fisheries, leading managers and decision makers to allocate resources to other research and management concerns (Beard et al., 2011). Previous studies (Welcomme et al., 2010) have projected that more accurate estimates of inland fisheries harvest could increase currently reported global inland fisheries harvest by as much as four-fold (Ellender et al., 2010; FAO, 2003; Welcomme, 2011).

The current lack of data on inland capture fisheries production and use has led policymakers to see inland capture fisheries as less of a priority and of less economic importance when compared to other services (e.g. hydropower, transportation, irrigation, municipal and industrial use) that freshwater can provide (UNEP, 2010). As a result, freshwater allocation is preferentially given toward other uses (e.g. irrigation, hydropower), leaving a reduced quantity or quality of freshwater available for inland fisheries production and few mitigation measures for those who depend on inland capture fisheries for food and livelihoods (Blumm, 1980; Dugan et al., 2010; Schlüter et al., 2009; Ziv et al., 2012). In some cases, policymakers may believe that the decrease in inland fisheries production and availability can be mitigated through increased development and use of aquaculture (Belton et al., 2014). Aquaculture is not always substitutable, however, for capture fisheries because it does not always mitigate the effects of decreased fish harvest (and consequently food and livelihood losses) stemming from reduced capture fisheries (Kawarazuka, 2010) for several reasons. First, because aquaculture often requires relatively costly inputs (e.g. feed, fingerlings, permits, pens or other ways to raise fish) and secure access to water and land, development of aquaculture may not be feasible for small-scale and subsistence fishers (Allison, 2011; Hishamunda, 2007; Lewis, 1997). Additionally, farmed fish species do not always provide the same nutrients as their counterpart wild species (Roos et al., 2007; Thilsted et al., 1997), possibly due to differences in diet and size between farmed and wild fish (González et al., 2006; Hamilton et al., 2005). Thus, careful consideration of the tradeoffs that will occur when freshwater use and allocation decisions are made is needed and proper mitigation measures implemented to ensure that those involved in inland fisheries are not left without an alternative source of food, nutrition, and livelihoods.

IV. Thesis format

This thesis is composed of two chapters, in addition to this introduction and a concluding synthesis. The goal of this thesis was to illustrate the importance of inland fisheries by describing the human health and nutrition benefits provided by inland fisheries (Chapter 1) and illustrating the use of household dynamics and consumption studies as a method of estimating inland fisheries harvest (Chapter 2). The first chapter presents a global overview of the food and nutrition benefits provided by global inland capture fisheries and the current threats to fisheries productivity and valuation. The second chapter further elaborates on the food benefits provided by inland fisheries and attempts to address the issue of lack of data in inland fisheries by proposing the use of household dynamics and consumption surveys to estimate inland fisheries harvest. Chapter 2 also provides several case studies in which household dynamics and consumption studies were applied in order to estimate inland fisheries harvest for a specific region. Two of the case studies also illustrate discrepancies between officially reported inland capture fisheries harvest and the (often much larger) harvest estimate obtained through use of household dynamics and consumption surveys.

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CHAPTER 1: INLAND CAPTURE FISHERY CONTRIBUTIONS TO GLOBAL FOOD SECURITY AND THREATS TO THEIR FUTURE

Youn, S., Taylor, W. W., Lynch, A. J., Cowx, I. G., Beard Jr., T. D., Bartley, D., and Wu, F. 2014. Inland capture fishery contributions to global food security and threats to their future. *Global Food Security, 3*(3-4), 142-148.

The content of this chapter is intended to be identical to the publication cited above and reflects journal specifications (e.g. formatting). Any differences should be minor and are unintended.

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.

Keywords: food; nutrition; freshwater fish; micronutrients; inland capture fisheries

I. 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 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.

II. Use and production of inland fisheries

i. 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 (Figure 1.1).

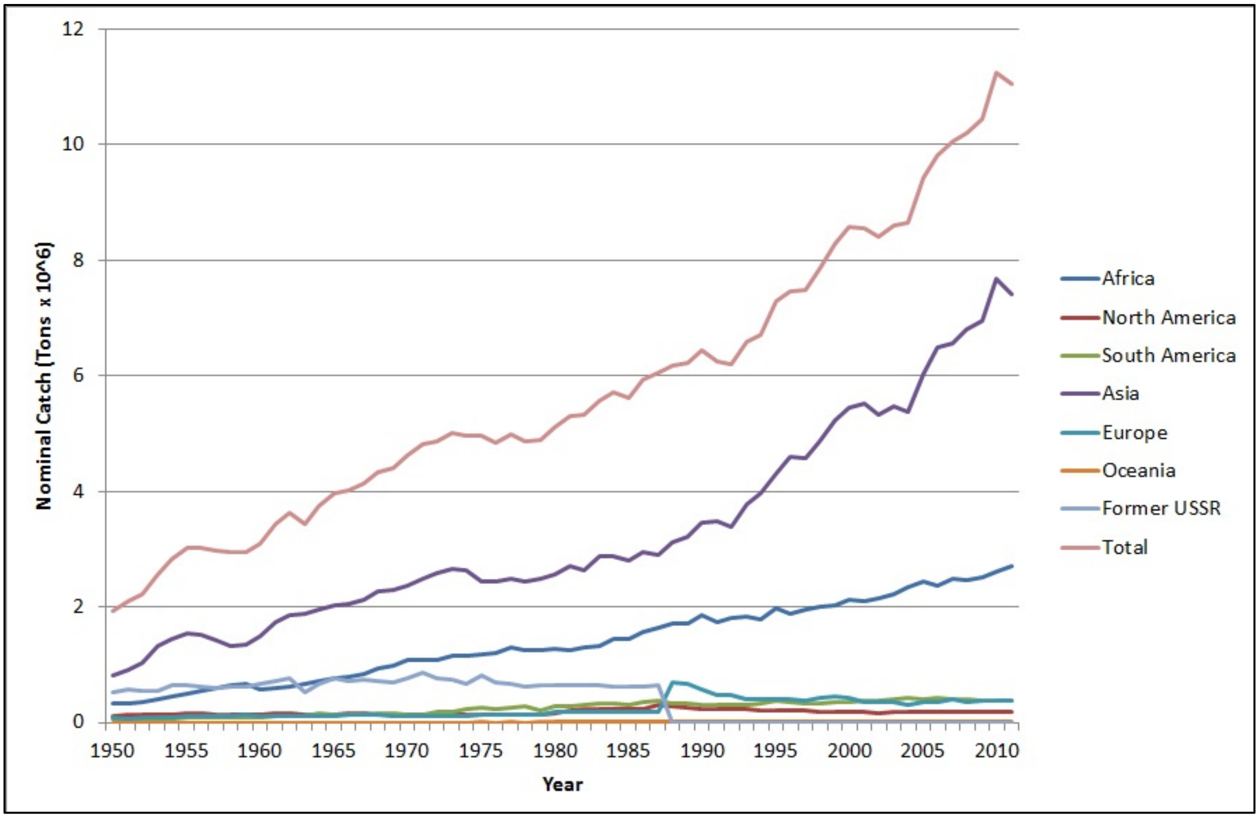

FIGURE 1.1. Global and regional production of inland capture fisheries as reported to FAO (FAO, 2014).

Based on harvest numbers reported to FAO, inland fisheries production comes predominately from Africa and Asia (Figure 1.1). 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).

ii. 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 (Figure 1.2).

iii. 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

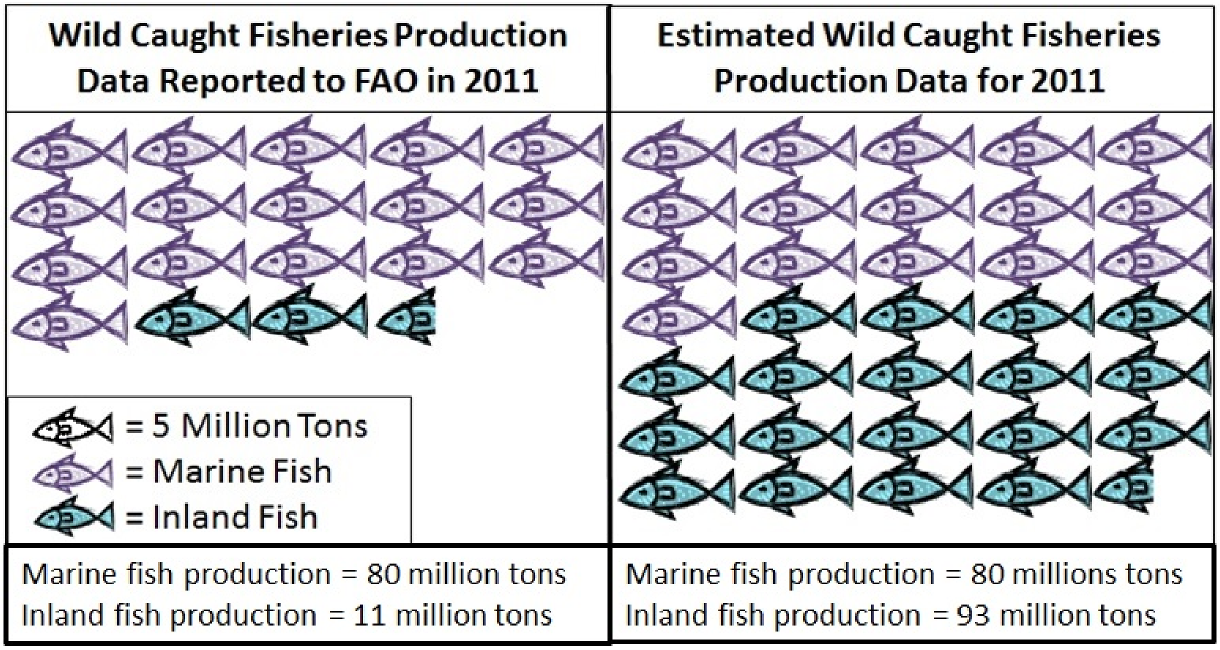

FIGURE 1.2. Graphical depiction of reported (FAO, 2012) and potential (Welcomme, 2011) global fish production for marine and freshwater fisheries.

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.

III. 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 1.1).

TABLE 1.1. 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., 2007 Chan et al., 1999
B vitamins	Energy production	Steffens, 2006
Vitamin A	Vision Tissue growth	Roos et al., 2007
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

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 *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).

IV. 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., 2007; 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.

V. 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 geo-spatial 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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CHAPTER 2: USE OF HOUSEHOLD DYNAMICS TO DETERMINE THE ROLE OF INLAND FISH IN LOCAL FOOD SECURITY

Youn, S., Taylor, W. W., Beard Jr., T. D., Welcomme, R., and Fletcher, R. *In Prep*. Use of household dynamics to determine the role of inland fish in local food security.

Abstract

Inland fish and fisheries play an important role in ensuring food and economic security throughout the world. Freshwater fish are especially important in the developing world, where they provide a critical source of animal protein, essential micronutrients, and livelihoods for local communities. Despite their importance to food security at a local and regional level, data concerning the importance of inland fisheries production and consumption are generally unavailable, often leading to the undervaluation of the importance of inland fisheries as a source of food and wellbeing by many policymakers. One way to obtain more accurate estimates of inland fish production is through the use of household dynamics, which evaluate the nature of changes in households and provides insight into family and individual behaviors. As such, these studies can quantify the nutritional and food importance of inland fisheries by providing insight into who is consuming fish, how much, and how often. This consumption data can then provide an estimate of inland fisheries harvest for the area, thus allowing for a more accurate assessment of the human health and wellbeing benefits provided by inland fisheries.

I. Introduction

Although most inland fisheries occur at the local and regional levels, they play an important role in ensuring food and economic security throughout the world (Welcomme et al., 2010). Freshwater fish production is especially important in the developing world, where they provide a critical source of animal protein, essential micronutrients, and livelihoods (Belton and Thilsted, 2014). Inland fisheries face many threats due to climate change, land and water-scape changes, and degraded water quantity and quality due to competing uses (e.g. irrigation, transportation, municipal use, hydropower, and other industrial uses) for freshwater. Tradeoffs of water usage and quality with these alternative freshwater uses impact fish habitat (including streams, rivers, and lakes) and production resulting in fewer fish available to surrounding communities.

i. Consumption of inland fish and food security benefits from inland fisheries

Inland fish are an important food and nutrition resource, especially in the developing world (Belton and Thilsted, 2014). These fish can be consumed either directly as part of a meal or indirectly as a major ingredient in feed for terrestrial livestock and aquaculture (Borin et al., 2000; UNEP, 2010). Of the estimated 11.6 million tons produced by global inland capture fisheries (12.7% of total global capture fisheries production) in 2014 (Figure 2.1; FAO 2014b), approximately 90% was used for direct human consumption (Welcomme et al., 2010).

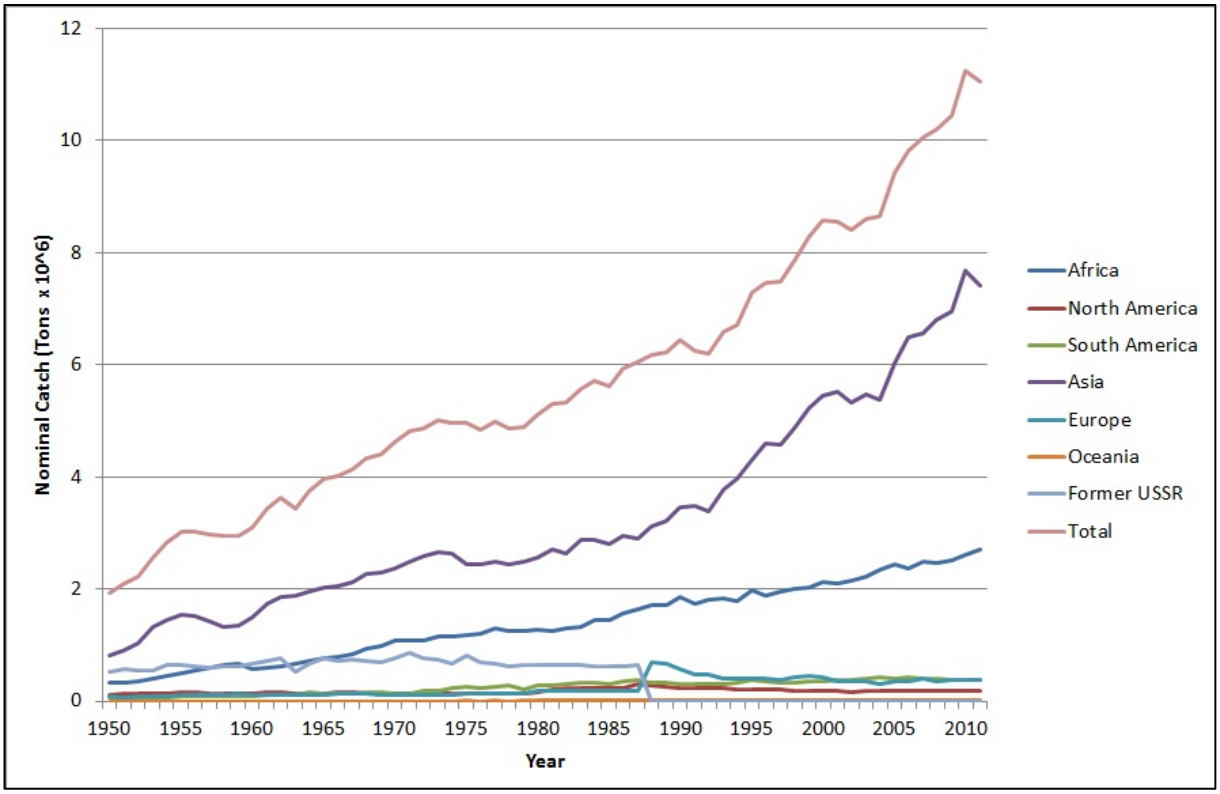

FIGURE 2.1. Inland fisheries production as reported to the United Nations Food and Agriculture Organization (FAO; FAO, 2014a).

Inland fish are also a vital source of protein and (when consumed whole) other nutrients, particularly calcium and vitamin A (Belton and Thilsted, 2014). In 2010, fish (both marine and inland) provided at least 2.9 billion people (about 40% of the global population) with nearly 20% of their animal protein and 4.3 billion people (about 59% of the global population) with 15% of their animal protein intake (FAO, 2014b).

The low monetary value often attributed to inland fish by policymakers and others does not accurately reflect the contributions of inland fish to human health (UNEP, 2010). In many areas, small native inland fish species (SIS) are the most accessible source of animal protein and other vital nutrients, especially for economically vulnerable households (Craviari et al., 2008; Thilsted et al., 1997). The important nutritional contribution of SIS, however, is not reflected in the low economic value attributed to these species (Roos et al., 2003). Unlike other foods high in animal protein (e.g. beef, chicken, pork), fish are often distributed more equally, both in terms of the amount of fish and the parts of the fish being consumed, among household members (Béné and Heck, 2005). As a result, the nutrients from inland fish are more equitably distributed among household members, especially women and children, rather than men receiving the majority of the food and nutritional benefits (Gomna and Ranna, 2007; Kyaw 2009).

ii. Economic importance of inland fish and fisheries

Employment and income generated from livelihoods in the fisheries sector and the associated supply chain (harvesting, processing, and marketing/trade) creates a direct contribution to economic security and an indirect contribution to food security by providing people with the economic means to buy food (Béné and Heck, 2005). Globally, more than 60 million people, over half of whom are women, are employed in the fisheries sector (Dugan et al., 2010). In Southern Laos, fisheries on the Mekong River have been verified to be the main source of animal protein and the largest source of cash income for local communities (Chong et al., 2003). In Vietnam, 14% of families work full-time in the freshwater fisheries sector (Dollar et al., 1998) while in sub-Saharan Africa, inland and coastal fisheries provide direct employment to 6-9 million people (Béné and Heck, 2005).

The relatively low start-up costs associated with inland fisheries can make them appealing to economically vulnerable groups, especially female heads-of-households (Welcomme et al., 2010). In many areas (e.g. western Africa, lower Mekong River Basin), women are able to catch fish, either for subsistence or livelihood purposes, on their own (Laë et al., 2004; Sverdrup-Jensen, 2002). Fish processing and trading sectors can also provide an important livelihood opportunity for women because jobs in these sectors, especially at the local level, require few investments and have low operational costs, can be conducted by unskilled labor, and do not require strong physical strength (Béné and Heck, 2005; Welcomme et al., 2010).

iii. Lack of inland fisheries data

Despite their importance to human health and livelihoods, information concerning inland fisheries harvest and use is generally unavailable or inaccurate. This lack of information often leads decision-makers, especially those more distant from the fisheries sector, to undervalue the importance of inland fisheries as a source of food and wellbeing. Production data may be poor because inland fisheries are geographically diffuse (e.g. fisheries on the Mekong river, subsistence fishing occurring in a small pond on private property), making it difficult to sample fish from all freshwater bodies or target the multitude of freshwater access points from which to obtain harvest numbers from fishers, especially subsistence fishers. Additionally, the infrastructure, labor force, or capital needed to generate production estimates or check the accuracy of existing estimates may be lacking (Thorpe and van Anrooy, 2009). In the Lower Mekong Basin (LMB), for example, fisheries agencies do not have the money or personnel to accurately monitor and record all inland fisheries harvest (USGS, 2012). Accounting for all harvest in the LMB, including subsistence, could increase total harvest amount from 645,254 tonnes (based on official country statistics) to a harvest value of 809,000 tonnes or higher (Baran et al., 2007).

iv. Use of household data to study inland fisheries consumption and harvest

Household food consumption data, which provides information on what households are eating and how often, can provide an estimate of inland fisheries harvest for local fishing areas. Unlike other harvest estimation methods, household dynamics studies reflect harvest by subsistence fishers, which is often missing from government estimates of inland fisheries harvest (Needham and Funge-Smith, 2014). A review by Chong et al. (2003) of Mekong River fisheries, for example, found that catch from many small-scale fishers were not included in the government's reported inland capture fisheries production values, in part due to the difficulty of measuring smaller water bodies. For a similar reason, in Thailand, the Thai Department of Statistics only reported inland fisheries production values from reservoirs and large wetland water bodies, which comprise roughly 2.7 million hectares of Thailand's roughly 4.9 million hectares of rivers, wetlands, reservoirs, and other freshwater resources (Pawaputanon, 2003). In general, use of consumption data have been found to be an effective method to estimate harvest in cases where fish harvest is primarily used for subsistence consumption (Léopold et al., 2004) which is the case for many inland fisheries, especially in the developing world (Welcomme et al., 2010).

Household dynamics, which evaluate the impacts of composition and socioeconomic changes in households (Rogers and Schlossman, 1990), can quantify the nutritional and food importance of inland fisheries by providing needed information concerning who is consuming fish, what types of fish are consumed, how much fish is consumed, and how often fish are consumed. This fish consumption information can provide an estimate of how much fish is being consumed in a given area and where that fish is coming from (e.g. locally caught or imported). Based on this information, a harvest estimate for that area could then be obtained. This harvest estimate is also a minimum ecological production estimate for the water body, since the harvest estimate gives an indication of how many fish must be produced in the water body to support the estimated harvest. The goal of this chapter is to describe the use of fish consumption data to estimate inland fisheries harvest and reveal the importance of inland fish to global food security, and present several cases studies, one from a developing country and one from a developed country, applying this method. The use of household consumption methodology has been applied to several areas in the developing world in order to estimate inland fish harvest and the contribution of inland fisheries to food security. Application of this method to developed areas, however, is much rarer. Applying this method in a developed country context (e.g. Michigan), provided a way to understand differences in how this method could be applied in a developed vs. developing country context and potential challenges in obtaining and using consumption data.

II. Methods

i. Conducting a fish consumption survey

Household dynamics is one way to generate fish consumption and harvest data. Household dynamics data can be collected through several methods, including participant observation and surveys. Household survey data can be collected from many different households but the information may be distorted by the biases of the respondent within each household (e.g. social desirability bias, being asked to report illicit or self-incriminating information). Participant observation can reduce some of this distortion since a third-party observer is recording the household dynamics data, but it is expensive and time-consuming to have observers in multiple households. As a result, survey data may provide information for a broader coverage of households in a region and be more cost effective than obtaining household dynamics data through participant observation. Household dynamics data can be

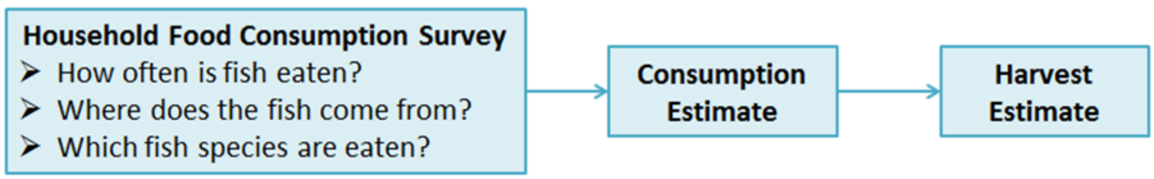

FIGURE 2.2. Schematic outlining the process of obtaining a fish harvest estimate from household surveys on fish consumption. Answers to the household food consumption survey can give an estimate of how much fish each household consumes (consumption estimate) and where the fish are caught or obtained from. Combining these results for every household in an area can give a harvest estimate for each water body identified as a fish source during the household survey. Both consumption and harvest estimates can be given in weight or number of fish consumed/harvested.

used to yield minimum estimates of the amount of fish obtained from a given water body (fish harvested from a given source) (Figure 2.2). In order to ensure that only harvest from a specified water body is estimated, the household survey should ask questions concerning the origin (e.g. imported from another place, bought at a local market, or caught by a member of the household) of fish that are being consumed. Surveys should also include questions regarding how often fish is eaten and what species are consumed in order to accurately determine fish mass and consumption frequency. Questions that address distribution of fish among household members (e.g. Is fish shared equally among all household members? Who eats which part of the fish?) can identify variations in the nutritional benefits individual household members receive since the nutritional benefits depend on how much fish is consumed and which parts. Differences in fish consumption among household members can also affect per-person fish consumption rate estimates if fish consumption is not equitable among all members of the household. Information concerning the livelihood impact from inland fish can also be obtained through questions which ask how the fish was obtained (e.g. Who catches the fish or buys the fish? Where was the fish caught or bought?). These questions can be asked in surveys and interviews specifically designed to measure the utilization of inland fisheries or can be added to existing food consumption and resource use surveys.

ii. Estimating inland fisheries consumption from survey data

Once the data regarding inland fisheries consumption have been obtained, a per-person consumption estimate ("Consumption Estimate" box in Figure 2.2) can be made using the following equation (Mayfield et al., 2007):

$$\text{Consumption Rate}\ \left(\frac{grams}{day}\right) = \frac{Meal\ Frequency\ \left(\frac{meals}{month}\right) * Meal\ Size\ (ounces) * Conversion\ Factor\ (28.35\,\frac{grams}{ounce})}{Averaging\ Time\ (30\,\frac{days}{month})}$$

Meal Frequency is the number of fish consumed per month (e.g. 2 fish consumed per month is equal to 2 meals per month). *Meal Size* is the weight of the fish portion that is eaten per meal. Visual aids (e.g. photo of fish portion size relative to plate size, 8 ounces of fish is roughly the size of an adult hand) can be used to help survey respondents report meal size. If meal size is not known, it can also be estimated by multiplying the average total weight of the fish species being consumed by 0.3 and converting the result to ounces (US EPA, 2014). The average weight is multiplied by 0.3 because the EPA estimates that, on average, the fillet of a fish is approximately equal to 30% of the total fish mass (Ebert et al., 1993). This estimate is conservative since fish weight (and consequently, meal size) will change depending on fish species, location where fish was caught, and fish condition. Additionally, the 30% estimate does not apply if less than one fillet is eaten per meal or other parts of the fish (other than the fillet) are consumed, which tends to be the norm in developing countries (Belton and Thilsted, 2014). *Conversion Factor* converts the meal size from ounces to grams and *Averaging Time* changes the consumption rate from "per month" to "per day".

Alternatively, a per-person consumption estimate can be obtained from fisher surveys using the following formula (Ebert et al., 1993; Mayfield et al., 2007):

$$\text{Consumption Rate}\ \left(\frac{grams}{day}\right) = \frac{Fish\ Mass\ \left(\frac{grams}{trip}\right) * Fishing\ Frequency(\frac{trips}{year})}{Household\ Size(persons) * Averaging\ Time(\frac{365\ days}{year})}$$

Fish Mass is the total amount of fish harvested per fishing trip. In cases where the exact fish mass is not known, estimates of average mass for fish caught in the same or similar locations may be available through government or other organizational records of fish species in the area (e.g. state Department of Natural Resources fish fact sheets, IUCN entries for fish species, MRC Mekong fish database) or in primary or secondary literature. Alternatively, if the length of the fish is available, fish mass can be estimated using a length-to-mass regression (Ebert et al., 1993). *Fishing Frequency* is the number of fishing trips the respondent makes per year and *Household Size* is the number of people within the fisher's household who also consume the fish the fisher harvests. *Averaging Time* changes the estimation time period from "per year" to "per day". Both formulas give consumption rate in grams/day per person as those are the units generally used by United States food consumption surveys (US EPA, 2014).

iii. Estimating inland fisheries harvest from consumption data

Surveys may report fish consumption in number of fish consumed rather than weight of fish or meal size consumed. In these cases the number of fish harvested would be equal to the number of fish consumed. If only consumption rate or meal size data are available, fish harvest can be estimated by converting the consumption rate or meal size values to total mass of fish consumed per given time period. Dividing this total mass value by estimated fish mass (average mass of 1 fish) gives an estimate of the number of fish harvested per time period (e.g. day, month, or year). Fish mass can be estimated using species-specific mass estimates (e.g. Department of Natural Resources fish fact sheets, IUCN entries for fish species, MRC Mekong fish database, primary studies) or by using the 30% fillet mass value (edible portion of fish is about 30% of total fish mass) used by the EPA (Ebert et al., 1993). This method assumed all fish that are harvested are consumed and there is no post-harvest loss of fish.

When estimating harvest, it would be most useful to obtain both total number and total mass of fish harvested; thus better reflecting the productive capacity of the aquatic ecosystem the fish come from. However, fisheries management policies often phrase regulations in terms of the number of fish that can be harvested. Thus, for purposes of informing management, it can be useful to know the total number of inland fish that are harvested. Alternatively, from an ecological or nutrition/food perspective, total mass is more commonly used than total number of fish. Thus, for these purposes, knowing the total mass of fish harvested or consumed may ultimately be more useful.

III. Case studies

i. Ayeyarwady Division, Burma (Myanmar) and Cambodian rice paddies

In Burma (Myanmar), most licensed fishers are generally commercial or large-scale fishers (FAO, 2003). Based on the harvest reported by licensed fishers, the Burmese (Myanmar) government estimated the inland fisheries harvest for the Ayeyarwaddy Division to be 90,813 MT in 1999-2000 (Figure 2.3). Household consumption studies in the area, however, report an

	Ayeyarwady Division, Burma (Myanmar)	Cambodian Rice Paddies
Estimated Harvest	90,813 MT	25-62 kg/ha/yr
Estimated Consumption	235,760 MT	119 kg/ha/yr
Difference	144,947 MT 260% Difference	57-94 kg/ha/yr 191-476% Difference

FIGURE 2.3. Reported harvest data is often much less than harvests suggested by consumption data. Data for the Ayeyarwady Division came from Coates (2002) and data for the Cambodian rice paddies came from Hortle et al. (2008).

inland fisheries harvest amount of 235, 760 MT, 2.6 times greater than the value reported by the government (Coates, 2002). This discrepancy partly occurs because many subsistence fishers do not have a license or do not report their harvest to the Department of Fisheries. As a result, values obtained from household consumption studies tend to be more reflective of total fisheries harvest than the Department of Fisheries estimate (FAO, 2003). Similarly, in Cambodian rice paddies, previously reported yield estimates of 25-62 kg/ha/yr were greatly exceeded by the 119 kg/ha/yr estimate reached through direct observation and monitoring of fish yield in the area (Hortle et al., 2008).

Household dynamics and food consumption data are often easier to collect than other methods of estimating fish harvest and provide important information on how fish are being used in local communities (Needham and Funge-Smith, 2014). Policymakers can then use this information to integrate inland fisheries into water management plans. By weighing the value of inland fisheries against the benefits and costs of other actions that would affect inland fisheries production, and by targeting policies to help those who are most dependent on the food and livelihood benefits provided by inland fisheries, policymakers will ensure that the decisions they make will not unduly adversely impact inland fisheries and those who depend on them (e.g. hydropower dams in the Mekong River basin; Ziv et al., 2012).

ii. Grand River, Lansing, Michigan, USA

Angler consumption data were collected as part of a research project (IRB approval i043719) looking at recreational urban fishing on the Grand River. From March 24 – October 31, 2014, angler consumption data were collected using an access site intercept survey (Robson and Jones, 1989) on 4 access points for the Grand river in the city of Lansing, MI (Moores Park, Riverside Park, Adado Riverfront Park, Burchard Park/Brenke Fish Ladder). Anglers were asked to identify which species they caught, which species (of the species they caught) they consumed, and how frequently (number of fish per month) they consumed each species of fish (Figure 2.4). All participating anglers were 18 years old or older, proficient in English, and

What species of fish do you catch and eat per month in the Grand River? (Check all that apply)	
_____ Fish Type	_____ Catfish
_____ Walleye	_____ Steelhead Trout
_____ Bass	_____ Crappie
_____ Perch	_____ Suckers
_____ Carp	_____ Bluegill
Whitefish	Other

FIGURE 2.4. Question regarding angler consumption of freshwater fish they directly harvest from the Grand River.

residents of the greater Lansing area. The survey schedule was designed so that each access site was surveyed at different times and days of the week throughout the sampling period. Surveying occurred twice per month for a period of 5 days each time (10 days total per month). The 5 day period was randomized each month in order to include both weekdays and weekends and covered times from 6:00am to 10:00pm. In total, responses were obtained from more than 450 anglers over the 2014 summer fishing season.

The angler consumption data were converted to weekly consumption rate using the following equation from Mayfield et al. (2007):

$$\text{Consumption Rate}\ \left(\frac{grams}{day}\right)$$

$$= \frac{Meal\ Frequency\ \left(\frac{meals}{month}\right) * Meal\ Size\ (ounces) * Conversion\ Factor\ (28.35\,\frac{grams}{ounce})}{Averaging\ Time\ (30\,\frac{days}{month})}$$

Meal Frequency was assumed to be equal to number of fish consumed per month (e.g. 2 fish consumed per month is equal to 2 meals per month). *Meal Size* was estimated by multiplying the average weight of the fish species by 0.3 and converting the result to ounces. The average weight was multiplied by 0.3 because the EPA estimates that the edible weight (fillet) of a fish is approximately equal to 30% of the total fish mass (Mayfield et al., 2007). If the respondent did not know how much fish they consumed per month, that respondent's freshwater fish consumption rate was estimated to be 0 grams/day. Average consumption rate (of each species) was estimated by averaging all consumption rates computed for each species (e.g. average consumption rate of bass, average consumption rate of bluegill).

Because most anglers gave their consumption estimate as number of fish eaten per month, harvest was estimated to be equal to the number of fish consumed by all anglers (export of harvest was assumed to be negligible). For anglers who gave their consumption estimate in pounds of fish per month, the number of fish consumed (harvested) was estimated by dividing the consumption estimate by the average weight of the fish. Because anglers were not asked for the average weight of the fish they caught, average weight values were provided by creel surveys conducted by the Michigan Department of Natural Resources (DNR; Michigan DNR, 2015) were used. In cases where an average weight from the Michigan DNR could not be found, average weights from either the Ohio DNR (Ohio DNR, 2012) or Wisconsin DNR (Wisconsin DNR, 2015), 2 Midwestern states close to Michigan, were used. Anglers who reported eating no fish were assumed to be releasing all fish they caught (harvest = 0). Anglers were assumed to eat only the fillet of the fish and fish consumption estimates were based on only the estimated weight of the fillet.

The angler survey resulted in a total of 799 responses (multiple responses per angler, depending on how many species the angler targeted or consumed) regarding fish consumption and harvest. Of these responses, based on specific species caught, 675 individuals (84.5%) responded they did not consume the specific species we observed they had caught. An additional 14 respondents reported they did not catch any fish and, for the fish consumption estimates, were assumed to not consume any fish. The most commonly harvested and consumed species were black bass (*Micropterus spp.*), bluegill (*Lepomis macrochirus*) and catfish (*Ictalurus punctatus*) (Table 2.1). Catfish and steelhead had higher average consumption

TABLE 2.1. Average consumption (g/day/person) and harvest (number/month) for 5 species harvested by anglers fishing the upper Grand River.

Species	Average Weight	Average Consumption Rate (grams/day/person)	Average Harvest (number of fish/month)
Channel Catfish (*Ictalurus punctatus*)	25lbs (Holtan, 1998)	161.86	228
Steelhead (*Oncorhynchus mykiss*)	9.5lbs (Michigan DNR, 2015b)	53.42	68
Yellow Perch (*Perca flavescens*)	7oz (Michigan DNR, 2015)	7.94	32
Bluegill (*Lepomis macrochirus*)	7oz (Mecozzi, n.d.)	7.82	448
Northern Pike (*Esox lucius*)	2lbs (Wisconsin DNR, 2008)	6.35	50
Bass (*Micropterus spp.*)	1.5lbs (Ohio DNR, 2012)	4.66	126

Rate than bluegill, however, due to the larger average weight estimates (Holtan, 1998; Michigan DNR, 2015b) found for catfish and steelhead. The larger weight of catfish and steelhead leads to a larger fillet size, so the edible portion (and consequently meal size) from a catfish or steelhead is much larger than the edible portion of a bluegill. As a result, although average bluegill harvest per month was the highest of any fish species, the low average weight of bluegill (Mecozzi, n.d.) meant that the edible portion was low and resulted in a low estimated per-person consumption rate. In particular, the unusually large average weight found for channel catfish greatly increases estimated consumption. If a more normal value (e.g. 3 lbs;

Illinois DNR, 2007) is used, average consumption decreases to a more reasonable 19.42 g/person/day (Table 2.2).

TABLE 2.2. Estimated average consumption of channel catfish decreases by 833% if an average weight of 3lbs (Illinois DNR, 2007) is used as opposed to the 25lbs weight found for Wisconsin (Holtan, 1998).

Species	Average Weight	Average Consumption Rate (grams/day/person)	Average Harvest (number of fish/month)
Channel Catfish (*Ictalurus punctatus*)	25 lbs (Holtan, 1998)	161.86	228
	3 lbs (Illinois DNR, 2007)	19.42	207
Difference		**833.47%**	**110.14%**

Overall, most respondents were not fishing for consumption purposes and freshwater fish do not seem to be an important food source for most respondents in this survey. The low proportion of anglers fishing for consumption may be due to anglers' interpretation of the questions asked or because fishing in developed countries seems to be primarily for recreation rather than subsistence. Of the 124 respondents (15.5%) who did report consuming the fish they harvest, average consumption rates tended to be above the average freshwater/estuarine fish consumption rate of 4.71 grams/person/day estimated by the United States Department of Agriculture (USDA) (Jacobs et al., 1998). The exception was bass, which had an average consumption rate of 4.66 grams/day/person. Anglers who do consume the fish they harvest meet the recommended 8-12 ounces/week (0.04-0.06 grams/day) fish consumption amount recommended by the US Food and Drug Administration (US FDA, 2014). Because of this, freshwater fish may be an important nutrient source for these fishers, which should be considered when making habitat restoration, water quality, and fishing regulation decisions for the Grand River.

IV. Discussion

Household dynamics and consumption studies are important tools to study the food and economic importance of inland fisheries. Using these studies to estimate inland fisheries harvest can also be useful because these studies account for harvest from subsistence fishing, which is often missing from official inland fish harvest estimates (Welcomme, 2011). In addition to providing information on inland fisheries harvest, household consumption data also provide, at the household level, information on the food and nutrition benefits people are receiving. Studying this information at the household level is important because it can show patterns in food consumption that are masked in consumption studies at the national or international levels (Rogers and Schlossman, 1990). For example, the USDA estimates US freshwater and estuarine fish consumption to be 4.71 grams/person/day (Jacobs et al., 1998). Tribal fishers in the US, however, have an estimated per-capita consumption rate of freshwater and estuarine fish that is much higher (142.4 grams/person/day; US EPA, 2000). Looking only at national freshwater and estuarine fish consumption, hides the substantial variation in fish consumption among different segments of the US population.

Another strength of using consumption data to estimate harvest is that, many times, consumption data has already been collected as part of previous studies (e.g. agricultural census, living standards survey) (Hortle and Bush, 2003; Kearney, 2010). Because these data have not been collected for harvest estimation purposes, however, there are some limitations. Ideally, all respondents would know which species they harvested and consumed, how much fish they consumed per meal, and how often they ate fish. Realistically, however, some information (e.g. meal size, fishing frequency, total fish mass per trip, average fish mass and meal frequency) may not be available and assumptions (e.g. fish fillet is equal to 30% of total fish mass) may have to be made (Ebert et al., 1993). Furthermore in developed countries, because fishing is often viewed as a recreational activity rather than a primary source of food (Beard et al. 2011), existing surveys and data likely focus more on amount or size of fish caught and less on the consumption aspects of inland fisheries.

Additionally the formulas provided use fishing and consumption values averaged over a set time period (e.g. one month or one year), implicitly assuming that fish consumption is constant throughout the year. Most likely, however, fish harvest and consumption probably vary seasonally throughout the year (Longley et al., 2014). Longer term studies looking at fish consumption throughout the year could provide more useful average consumption estimates. Alternatively, consumption estimates could be reported per season (e.g. fish consumed in grams per person per month during the rainy season) in order to reflect possible seasonal differences in consumption.

Despite these limitations, however, consumption and harvest estimates derived from household dynamics and consumption estimates provide an important method for addressing the lack of information that affects inland fisheries (Dey et al., 2008; Hortle, 2007). As seen in the *Case Studies*, official harvest estimates can be far below actual harvest rates once subsistence fishing is accounted for (Coates, 2002; Hortle et al., 2008). The Grand River, MI case study also demonstrates the potential for use of consumption estimates to estimate inland fisheries harvest and provides inland fish harvest estimates for an area for which no previous harvest estimates exist. The consumption estimates also indicate that anglers who consume the fish they harvest eat meet or exceed the fish consumption amount recommended by the FDA in order to obtain important nutrients from fish (US FDA, 2014).

More accurate consumption estimates would provide more information regarding inland fisheries harvest and the contributions of inland fisheries to human food, nutrition, and livelihoods, especially in developing countries. This information could then be provided to policymakers to incorporate into decisions regarding freshwater use and allocation and so that policymakers will be aware of the potential consequences of decisions that could reduce fisheries productivity and consequently, harvest. The contributions freshwater fisheries make will also be important as future climate changes, landscape changes, and increased demand for freshwater (from hydropower, agriculture, municipalities, transportation, and other industrial users) impact the quantity and quality of water and fish habitat (Mirza and Ericksen, 1996; Timmers, 2012). In order for the people who depend on inland fisheries for food and livelihood to continue to receive these health and wellbeing benefits, it is necessary to know how climate change and alterations in land- and water-scapes will affect their food security and livelihoods (Ziv et al., 2012). This information can then be utilized in freshwater allocation and landscape alteration decisions to ensure that inland fisheries are accounted for in decision-making processes and, if these decisions will decrease inland fisheries harvest, negative impacts on local health and wellbeing are mitigated.

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SYNTHESIS

I. Changes in local and regional inland fisheries productivity

Inland capture fisheries are an important global food and livelihood resource, particularly in the developing world (Belton and Thilsted, 2014). In many areas they are the most affordable source of animal protein (Mohan Dey et al., 2005) and provide essential nutrients (particularly calcium, zinc, and vitamin A) that are critical for human growth and development (Bogard et al., 2015). Climate change and land- and water-scape changes, however, threaten inland fisheries productivity and the food security and livelihoods of those who depend on inland fish resources.

Climate change and land- and water-scape changes will impact the quantity and quality of freshwater available (Eastham et al., 2008), which can negatively impact fisheries productivity (Lynch et al., 2011; McCartney, 2009). In addition to directly reducing the quantity and quality of habitat available for freshwater fish (Dugan et al., 2010; Hayes et al., 1996), these changes will also intensify demand among freshwater use sectors (e.g. hydropower, agriculture, transportation, municipal use, and fisheries) for limited freshwater resources (UNEP, 2010). Consequently, policymakers should carefully evaluate the tradeoffs involved when allocating freshwater use to each sector. In cases where water use would impact fish productivity and harvest, mitigation measures (e.g. training to transition livelihoods, provision of alternate food and nutrition sources) should be implemented so that the people who use inland fisheries are not left without alternate means of obtaining food, nutrition, and livelihoods. Knowing what mitigation measures are necessary depends on having accurate information regarding inland fisheries harvest and use and the impact of other freshwater user sectors on inland fisheries.

Because many regions do not have the resources or infrastructure to survey every water body on which inland fisheries exist (FAO, 2012), other methods must be used to obtain this production, harvest, and use information. This thesis presented one method, use of consumption data, as a way to address this information gap.

II. Use of alternative methods to estimate inland fisheries harvest

Household dynamics and consumption studies are one method that can be used to provide inland fisheries harvest estimates. These studies offer several advantages over other methods used to estimate inland fisheries harvest. First, household dynamics and consumption data have already been collected in many areas as part of national living standards surveys or for other uses (Ebert et al., 1993; Kearney, 2010). These surveys usually contain questions on fish consumption and origin (e.g. self-caught or market, freshwater/estuarine or marine) (US EPA, 2014). In addition to their original purpose these data can also be used to estimate inland fisheries harvest using the methods described in Chapter 2. Second, household dynamics data give insight into fish harvest as well as utilization of inland fisheries (e.g. used for livelihoods, food, recreation, or some combination of those 3), which contextualizes the value of fish harvest in terms of its contributions to household food security and livelihood (Baran et al., 2007; Hori et al., 2011). Third, use of consumption-based approaches to measure harvest provides accurate estimates in areas where the main use of fish harvest is subsistence consumption, which is the case for the majority of inland fisheries (Dey et al., 2008). At the local level in particular, consumption estimates are an accurate reflection of inland fish harvest (Hortle, 2007).

Due to these benefits, household dynamics studies can be an effective method for obtain inland fisheries harvest estimates in areas for which no estimates currently exist. Harvest values estimated from these studies can also be compared to existing harvest estimates (e.g. government statistics or harvest estimates derived using market surveys, biological surveys) in order to verify the accuracy of harvest estimates obtained using these methods. More accurate harvest values can then be used to evaluate the food security and livelihood benefits inland fisheries provide and the potential consequences to human health and wellbeing if inland fisheries production (and as a result, harvest) were to decrease.

Use of household dynamics studies, in conjunction with other methods, can address the important issue of lack of data in inland fisheries and inform policymakers and others of the important contributions inland capture fisheries make to human health, livelihoods, and wellbeing. Inland fisheries should also be integrated into water use and management decisions, both during the decision-making process and in consideration of the tradeoffs that water use decisions entail (e.g. water for one use means less water, and potentially lower quality water, available for other uses). When making water allocation decisions that impact water quantity and quality, the effects on inland fisheries productivity should be considered by policymakers. If productivity will decrease, mitigation measures should be created so that the health and wellbeing of the people who depend on inland fisheries for food and livelihoods will not be harmed.

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