15

Sustainable inland fisheries – perspectives from the recreational, commercial and subsistence sectors from around the globe

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15.1 INTRODUCTION

Globally, freshwater ecosystems provide varied fishing opportunities (herein termed inland fisheries) represented by three sectors: recreational, commercial and subsistence fisheries. From the depths of the Laurentian Great Lakes to the shallow floodplains of the Ganges River, and from under-ice fisheries in Scandinavia to the rice fields of Southeast Asia, fish and other aquatic life are omnipresent components of fluvial and lacustrine systems. Freshwater fishes generate many ecosystem services that extend beyond their use in fisheries (Holmlund & Hammer, 1999; Cowx & Portocarrereo, 2011). Given the diversity of freshwater fish assemblages, levels of fisheries productivity, cultural norms, density of human population and socioeconomic conditions, it is not surprising that there is immense variation in how, why and the extent to which freshwater fishes and other aquatic animals are exploited. Whether it be sustaining livelihoods through the provision of essential nutrients, generating income, or enabling leisure time with family, inland fisheries are important. Although there are accepted definitions for the three fishing sectors (i.e. UN FAO – see below), ambiguities and exceptions remain that complicate appraisal and management.

Compared with marine waters where industrial-scale commercial fisheries predominate, inland fisheries tend to be smaller in scale and catches generally do not enter the global marketplace. Moreover, whereas

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exploitation pressures are the primary threat facing marine fish popul
tions and marine ecosystems, in inland systems there are multiple threat
including many unrelated to fishing (Arlinghaus *et al.*, 2002). Indeec
declines in freshwater fish fauna are implicated with broad-scale ecc
nomic activities such as flow regulation, hydropower, agriculture, urbar
isation and pollution (Limburg *et al.*, 2011; Chapters 4 and 9). Reflectin
the multiple threats, freshwater fishes are among the most imperille
taxa on the globe (Strayer & Dudgeon, 2010; Chapter 2), freshwater bic
diversity is in crisis (Dudgeon *et al.*, 2006) and freshwater ecosystems ar
among the most altered (Kennish, 2002; Malmqvist & Rundle, 2002
Despite the many threats to inland fishes and fisheries, they receive dis
proportionally less interest and attention from the global conservatio
community and international political spheres. Indeed, global captur
statistics underrepresented inland fisheries and their contribution t
global production (Welcomme *et al.*, 2010; Welcomme, 2011a,b), partl
because of the diffuse nature of inland fisheries (Beard *et al.*, 2011). B
contrast, it is comparatively easy to generate data for commercial fishe
ies where products sold on established domestic and export markets ca
be readily monitored. In recent years, there have been attempts to bet
ter characterise the magnitude and scale of inland fisheries (Welcomme
2011a,b). Such efforts are aimed at generating a more realistic picture o
how inland fisheries contribute to food security and generation of income
as well as to identify potential conservation issues (Beard *et al.*, 2011).

Although still imperfect, statistics from inland fisheries reveal
steady increase from 2.0 million tonnes in 1950 to 11.6 million tonne
in 2011 (Figures 15.1 and 15.2). The increase is attributed largely t
improvements in monitoring and reporting, rather than real increase ir
harvest (Welcomme, 2011a). Inland water catches, however, appear to b
underreported by an average of 70% (World Bank, 2012). For example
the reported catch for Vietnam in 2003 was 203,000 tonnes, but the
true catch is closer to 1 million tonnes (World Bank, 2012). Although
inland fisheries harvest is only ~10% of that from marine systems, it is
massively important on a regional basis for food security, especially in
remote, rural areas (Welcomme *et al.*, 2010). Indeed, ~38% of inland fish
capture is from the 71 low-income food deficit countries (as defined by
the FAO; Welcomme, 2011a). Globally, inland capture fisheries generate
2.3% of total animal protein sources, although the contribution of fish
to diet varies widely among countries and regions (Welcomme, 2011a).
Inland fish are also targeted by millions of recreational anglers across
the globe (Arlinghaus *et al.*, 2002; Arlinghaus & Cooke, 2009). Relevant
here is that the recreational sector is quite large, they are not accounted

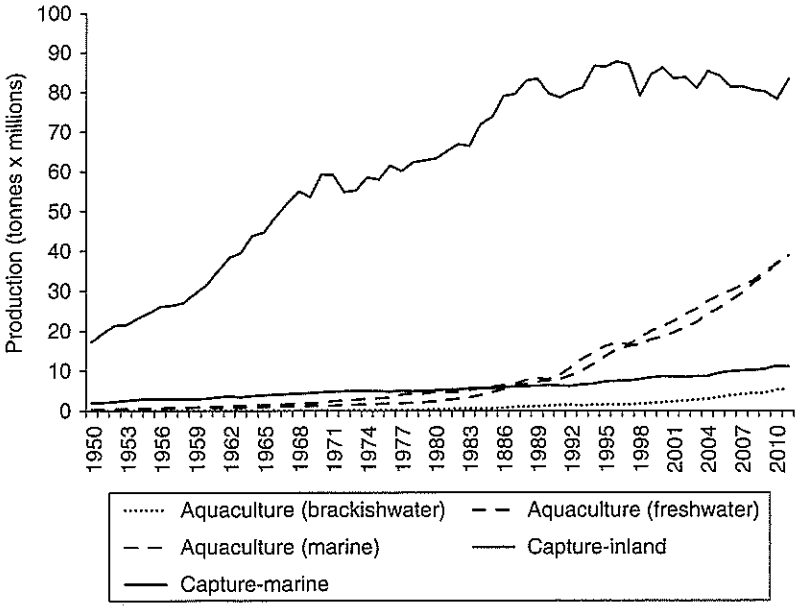

Figure 15.1 Summary of UN FAO statistics illustrating global capture for marine and inland systems as well as global aquaculture production by water body type.

for in FAO statistics, and when economic development occurs, there tends to be a transition from commercial-subsistence fisheries to recreational fisheries (Arlinghaus *et al.*, 2002; Cowx *et al.*, 2010; FAO, 2012), and under these circumstances there is often a reasonable proportion of catch that is released (i.e. catch-and-release). The majority of reported capture (90%) in inland fisheries is for finfish with crustaceans and molluscs locally important in some regions (Welcomme, 2011a,b), although it should be recognised the latter are largely unreported as they pass through informal markets. About 19 million fishers participate in inland fisheries, and inland fisheries support a workforce of 58 million people (World Bank, 2012).

Existing syntheses on inland fisheries have tended to focus on different sectors and their interrelationships (e.g. Welcomme *et al.*, 2010; World Bank, 2012), but not on specific interactions. Given that it is more the rule than the exception for multiple fisheries sectors (two or three) to co-occur in the same region or water body, it would be informative to consider their interactions when characterising inland fisheries and identifying what is needed to achieve sustainable inland fisheries. In the present paper, we adopt a regional case study approach on inland fisheries interactions with a focus on areas where two or three fisheries

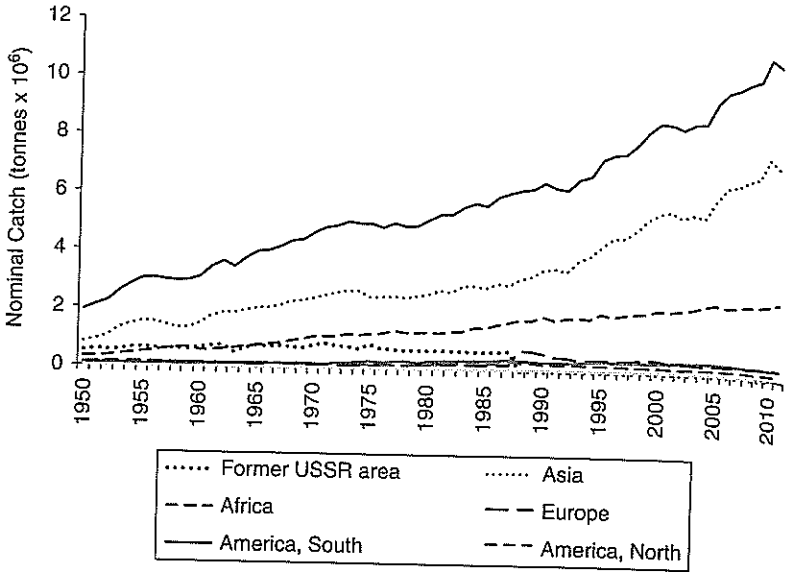

Figure 15.2 Summary of UN FAO statistics for inland fisheries relative to different regions.

sectors co-occur. We preface the case studies with a brief overview of the three fishing sectors acting in inland waters and their characteristics. We then explore the similarities and differences emerging from the case studies to identify general principles related to threats and conservation. We also consider what is needed to chart a course towards a future of sustainable inland fisheries.

15.2 CHARACTERISTICS OF INLAND FISHERIES

Here, we briefly summarise the characteristics (in terms of gear and magnitude) of the three fisheries sectors in inland waters and associated benefits to humans. The definitions for each sector are derived from the FAO Glossary.

15.2.1 Recreational fisheries

Defined as fishing for aquatic animals that do not constitute an individual's primary resource to meet nutritional needs and are not generally sold or otherwise traded on export, domestic, or black markets.

Recreational fisheries in inland waters are described elsewhere in detail (e.g. Arlinghaus *et al.*, 2002; Cowx, 2002; Arlinghaus & Cooke,

2009; FAO, 2012); therefore, we only provide a brief refresher here. Fishing with rod and reel (i.e. angling) is the most common recreational fishing technique (Arlinghaus *et al.*, 2007). However, in some countries, recreational fishers often use other gears such as spear, bow and arrow, rifle, traps, or gill nets (Arlinghaus & Cooke, 2009). Fish are taken home for personal consumption in some jurisdictions, but an increasingly large proportion of fish is released either because of the conservation ethic of the angler, culinary dislike, too many or few fish, or to be compliant with harvest regulations (Arlinghaus *et al.*, 2007). Recreational fisheries can target wild fish or focus on stocked fish (sometimes as put-grow-take fisheries), at times in artificial systems (e.g. ponds). Recreational fisheries constitute the dominant or sole user of many wild freshwater fish stocks in most industrialised countries (Arlinghaus *et al.*, 2002). Globally, approximately 10.6% of the population participate in recreational fishing, but there is insufficient information to partition participation by inland and marine waters (Arlinghaus & Cooke, 2009). Recreational fishing is booming in emerging economies (e.g. India, Brazil) and very popular across the industrialised world, with hundreds of millions of people engaged in the activity (FAO, 2012).

Spatiotemporal closures, bag limits, gear specifications, species/size restrictions and mandatory catch-and-release are various regulatory tools used by recreational fisheries managers (typically in developed countries) to reduce overexploitation and maintain stock structures. Stock enhancement (stocking and introductions), on the other hand, is commonly used to enhance stock of fish in a river or lake system, to create new fisheries, promote angling diversity, improve recruitment and/or maintain productive species (Cowx, 1994; Cooke & Cowx, 2006). Stocking activities can threaten native stocks through competition, predation, reduced genetic diversity, or spread of novel pathogens and parasites (Cowx, 1994). Alternatively, recreational fisheries managers may focus on habitat management to mitigate, rehabilitate, or restore the structure and function of aquatic ecosystems as well as the natural reproduction of recreationally valuable fish populations. In some regions, such as North America, most waters are public access with fisheries managed by natural resource agencies for the public good. In Europe there is a tendency towards private ownership of inland fisheries rights with the expectation that much of the management is the responsibility of the owners (e.g. angling associations; summarised in Arlinghaus *et al.*, 2002).

The socioeconomic benefits of recreational fisheries are numerous and substantial, particularly in inland systems (Arlinghaus *et al.*, 2002; Arlinghaus & Cooke, 2009; Parkkila *et al.*, 2010). Benefits can be viewed from the perspective of the angler and the broader angling community (e.g. tackle manufacturers, guides), as well as the whole of society (Arlinghaus & Cooke, 2009). The whole suite of individual benefits received by anglers is also subsumed within the concept of economic value (Parkkila *et al.*, 2010).

Recreational fishing in inland systems comprises a multibillion dollar global industry that supports economic activity and livelihoods for many (Arlinghaus *et al.*, 2002). There is also the above-mentioned economic value for the individual fisher, where the participation in recreational fishing creates utility over and above the expenditures needed to participate in fishing, often measured as willingness to pay for a fishing experience (Parkkila *et al.*, 2010). In some inland systems, expenditure by recreational fishers represents significant revenues and jobs. Unfortunately, global estimates of the economic value of inland recreational fisheries are lacking, but it is certainly in the hundreds of billions of USD.

15.2.2 Commercial fisheries

Defined as fisheries whose primary aim is to provide resources to meet human nutritional (i.e. essential) needs; in both full-time and part-time commercial fisheries, fishes and other aquatic organisms are sold on domestic and export markets; commercial fisheries include those that supply feed to the aquaculture and agriculture sectors and raw material to other industrial sectors (e.g. biomedical sector).

Commercial fisheries in open marine waters are commonly carried out by large fleet vessels operated by large crews of fishers. Inland water commercial fisheries are usually small-scale (Welcomme, 2001). Globally, there are approximately 1.13 million fishing vessels in inland waters (FAO, 2012). In some areas, fishing gears used in inland fisheries are highly diverse and adapted to exploit the diversity of habitats, species and seasonality. In rivers, fishing gears can be quite complex. For instance, over 114 gears have been described for the lower Mekong River (Deap *et al.*, 2003). In lakes, gears are typically less complex and can include: seines, gillnets, longlines, castnets, trapnets, electrofishing and small trawls (Welcomme, 2011a). Small-scale fishers operate using small craft such as canoes and rafts (with or without outboard motors); whereas industrial fishers require commercial permits and use efficient technologies that have high harvest capacities (De Jesus & Kohler, 2004).

The larger commercial fisheries (e.g. Laurentian Great Lakes, Lake Victoria, the Mekong River) are amongst the most regulated type of the three fishing sectors and contribute much of the data used to estimate global inland fisheries production. Various regulatory constraints help prevent overexploitation of the resources and include spatial and temporal season closures, harvest quotas (catch limits), licensing, gear restrictions and restriction on size and species of harvested fishes (Cooke & Cowx, 2006). Although by-catch does occur in inland systems (Raby *et al.*, 2011), much of it is retained and used, in contrast to many marine systems.

The socioeconomic importance of inland commercial fisheries and their role in the livelihoods of rural households, particularly in developing countries, are significant and often underestimated (Welcomme *et al.*, 2010). Inland commercial fisheries contribute significantly to the livelihoods of millions of people as a source of income for both families of full-time fishers, and for households that live close to water bodies and engage in part-time commercial (i.e. artisanal) fishing. Fishing is necessary to local populations who depend on this activity to access cash quickly and it provides labour for unskilled workers who rely on fishing for income and sustenance (Welcomme *et al.*, 2010). They also contribute to food security, generate revenue with low capital investment, provide monetary resources in times of need, and dissipate risks resulting from crop failures (McKenney & Tola, 2002).

15.2.3 Subsistence fisheries

Defined as fishing for aquatic animals that contribute substantially to meeting an individual's nutritional needs; in pure subsistence fisheries, fishing products are not traded on formal domestic or export markets but are consumed personally or within a close network of family and friends; such fisheries sustain a basic level of livelihood and constitute a culturally significant food-producing and distributing activity.

The difference between subsistence fisheries and the two other sectors is somewhat obscure. In general, if fishing activity supports direct nutritional needs to the family that is difficult to be substituted by alternative food, it would be subsistence rather than recreational. A large number of subsistence fishers participate in inland fisheries, where their products are generally marketed and consumed locally at the point of capture. Subsistence fishers often engage in part-time fishing because they are also involved in other economic activities such as farming or construction when fish catches are low (Welcomme, 2011b), where households may switch from no fishing to subsistence fishing to commercial

fishing relative to opportunities and seasonality. Subsistence fishers may harvest individual fish using gears such as rod and reel, spears, dip nets, harpoons or hand lines. They may also catch multiple fishes to provide food for their families and communities using gear similar to that used in small-scale artisanal commercial fisheries (e.g. seines, gillnets, cast nets). An overlap exists between subsistence fisheries and both the recreational and commercial (i.e. small-scale artisanal) fishing sectors. Although recreational fishers engage in fishing for leisure, they may also decide to keep their catch for consumption. Subsistence fishers will also keep their catch for consumption while also trading a portion of the catch at local markets for cash or other products and services. In part, subsistence fisheries are a component of small-scale commercial fisheries with a focus on household consumption rather than commercial activity (World Bank, 2012).

Subsistence fisheries are often informal and catches are rarely sampled or reported because the catch goes directly to domestic consumption, often in cryptic locations (Welcomme, 2001). Even frequently overlooked systems like small lakes, streams and rice paddies support subsistence fisheries (Brummett *et al.*, 2010). Household consumption surveys have been used to estimate fish that avoided passing through formal market chains or recording checkpoints, but because catches are two steps removed from the fishery, information on the origin of the fish consumed is often lost (Welcomme, 2011a). For example, findings from studies of fish consumption in the Mekong Delta (Vietnam) suggested that inland capture fisheries production is five times greater than official reported statistics (World Bank, 2012). Some countries, such as Peru, have expanded their commercial harvest data by 30% to correct for the absence of subsistence reporting (De Jesus & Kohler, 2004). Lymer and Funge-Smith (2009) reassessed Asian inland catch statistics by accounting for countries with large annual increments in fish production. In general, subsistence fisheries are obscure and complex. Understanding and quantifying harvests from these fisheries can be challenging, but critical to assessing global catch estimates and the impacts on livelihoods of river inhabitants.

15.3 CASE STUDIES

What follows are seven case studies from multisector inland fisheries around the globe to provide insight on the interaction among different types of fisheries and its relationship to fish biodiversity conservation. The case studies are focused on larger systems, but the primary themes are likely relevant to smaller systems.

15.3.1 Laurentian Great Lakes fishery

The Laurentian Great Lakes of North America hold 21% of the world's supply of accessible fresh water. The Great Lakes basin straddles Canada and the USA, and is home to more than 30 million people. The Great Lakes serve important roles in terms of transportation, irrigation, recreation and food production. They are ever-changing with respect to the fish assemblages as a result of many intentional (e.g. Pacific salmon) and unintentional (e.g. sea lamprey, round goby) introductions of fish and other organisms (e.g. dreissenid mussels). Recreational and commercial fisheries co-occur on all of the Laurentian Great Lakes with aboriginal subsistence fisheries occurring in discrete locations and often during discrete periods. The economic impact of these fisheries is large, valued at US$7 billion in US waters (American Sportfishing Association, 2008). Commercial fisheries are the dominant form of extraction in Canadian waters, whereas recreational fisheries predominate in US waters. There are, however, viable commercial fisheries in the US, especially for yellow perch (*Perca flavescens*) in lakes Michigan and Erie, and by US tribal governments for lake whitefish (*Coregonus clupeaformis*). An element of the very large recreational fishery on the US side is the charter fisheries for salmonides, walleye (*Sander vitreus*) and yellow perch. In many cases, the recreational and commercial fisheries coexist without extensive conflict because they target different species, the harvest allocation is primarily for either the recreational or the commercial sector, they are separated in space and (or) time, or the harvest rate does not put undue pressure on fish populations. Aboriginal subsistence fisheries, at times, conflict with other sectors. However, this is typically only on a very site-specific basis, usually related to allocation. In the USA, such fisheries are governed by tribal treaty rights, and in Canada, aboriginal subsistence fisheries are protected under the Canadian Constitution. In general, few members of the aboriginal community are fully engaged in subsistence harvesting. Nonetheless, the aboriginal harvest is shared with many throughout the community and has high cultural value.

There is substantial potential for conflict between the recreational and commercial sectors, particularly for walleye and yellow perch, which are prized by commercial and recreational fishers alike. Management of the Lake Erie fishery offers insight into how these fisheries and their potential conflicts are managed in a cooperative, bi-national manner. Cooperative fishery management in the Great Lakes occurs in a non-binding, consensus-based approach as outlined in *A Joint Strategic Plan for Management of Great Lakes Fisheries* (Gaden *et al.*, 2009). As

such, all of the jurisdictions with fishery management authority in Lake Erie (Ontario, New York, Pennsylvania, Ohio and Michigan – the Lake Erie Committee) meet, at least annually, in a public forum to decide on management goals, objectives and actions, including the total allowable catch (TAC) for walleye in the quota management zone of western and central Lake Erie, and for yellow perch lakewide. The jurisdictions have agreed to share the TAC based on the amount of habitat for each species in each jurisdiction. For example, the TAC allocated by the Lake Erie Committee (LEC) for walleye in the quota zone for 2012 was 3.49 million fish (LEC, 2012). Within this allocation, Michigan was allocated about 200,000 fish, Ohio about 1.78 million fish, and Ontario around 1.50 million fish. Ontario allocates nearly its entire quota to the commercial sector, whereas Michigan and Ohio allocate all of their harvest to the recreational sector (including charter fisheries). While this practice works well in theory, conflict can arise because the recreational fishery frequently does not harvest its entire assigned quota, leaving commercial fishers questioning why they should not be allowed more of the lake-wide quota. Similarly, recreational anglers who value the opportunity to catch older, larger walleye view the possibility of commercial over-harvest as one that will jeopardise their ability to catch trophy fish.

Although the LEC has generally worked well internally to resolve potential disagreements about quota levels, they have occasionally needed to use dispute resolution procedures (Gaden, 2007). More problematic in recent times has been the distrust between the recreational and commercial sectors about each group's motives and, by extension, the motives of the management agencies associated with each group of fishers. Both managers and resource users recognised the need to directly work together in an open, transparent forum to come to agreement on the future of these fisheries – a process that is currently under way.

Collectively, the recreational, commercial and subsistence fisheries of the Laurentian Great Lakes are reasonably sustainable, given the expected caveats associated with ongoing ecosystem impacts of invasive species, possible future ecosystem shifts due to climate change and changing land-use patterns. Cooperative fishery management across jurisdictional boundaries, stakeholder involvement and strong science help to make this status possible. Nevertheless, the status of exploitable fish populations can change quickly, reinforcing the need for strong science to identify potential population-level changes, managers willing to take appropriate action, and transparent communication among all parties to ensure the future sustainability of these important fisheries.

15.3.2 Mississippi River fishery

The Mississippi River (MSR) is among the world's most important river systems with regard to its size, physico-chemical and biological diversity, and socioeconomics. Its watershed covers about 40% of the surface area of the lower 48 US states, and includes all or portions of 31 US states and 2 Canadian provinces. The MSR and its larger tributaries (Missouri, Ohio and Illinois rivers) played an important role in Native American cultures, and since European settlement, the system has been central to the social and economic development of the USA. While much has changed within the MSR and its watershed, one relative constant has been the importance of fishery resources.

The MSR originates at Lake Itasca, Minnesota, and flows ~820 km to St Anthony Falls, Minnesota. This reach is commonly referred to as the headwater (HW) reach. A number of small dams have been constructed for flood control, power generation, municipal and industrial water supply and recreation. The reach (~1100 km long) from St Anthony Falls, to Alton, Illinois (just upstream of the Missouri River confluence) is the upper Mississippi River (UMR). The UMR has been impounded by 29 locks and dams to provide a minimum channel depth (2.7 m) for navigation, but the reach maintains a high level of habitat diversity relative to downstream reaches. From Alton, the MSR flows unimpounded for ~1800 km to Head of Passes, where it branches into smaller systems that terminate at the Gulf of Mexico. The middle Mississippi River (MMR) is typically defined as the reach from the mouth of the Missouri River to the mouth of the Ohio River, and the lower Mississippi River (LMR) is from the Ohio River to the Head of Passes. A continuous levee system was constructed in the 1930s that disconnected the river from its floodplain. Although discharge and the size of the channel differ between the MMR and LMR, they share similar hydrology, levels of water development and fish assemblages.

The MSR has long provided a subsistence fishery for inhabitants near the MSR. Based on accounts of early explorers and settlers, the MSR provided important resources for Native Americans, including aquatic vertebrates (e.g. fishes, turtles, mammals) and invertebrates (e.g. unionid mussels; Brown *et al.*, 2005). Like most subsistence fisheries, use of fishing the MSR was dependent on the spatial and temporal availability of resources. While a diversity of fishery resources were undoubtedly used throughout the year, accounts indicate that catostomids, acipenserids, paddlefish, esocids and ictalurids were particularly important in subsistence fisheries (Carlander, 1954). Current use of the

fishery resources for subsistence is small compared with commercial and recreational fisheries.

The MSR has a long history of supporting commercial fisheries. The HW reach historically supported small, local commercial fisheries, but this is no longer the case. Rather, most commercial fisheries are in the UMR, MMR and LMR. The best records of commercial harvest are from the UMR, where the Upper Mississippi River Conservation Committee (UMRCC; composed of state and federal natural resource managers from Illinois, Iowa, Minnesota, Missouri and Wisconsin) has compiled commercial harvest data for the UMR since the late 1940s. Total landings of fish in the UMR have varied considerably among pools and years. For example, total landings in the UMR were 6.2 million kilograms in 1894 (Carlander, 1954) and 3.1 million kilograms in 2006 (MCQ, unpublished information). Commercial landings also vary spatially, where in 2006, total harvest varied from ~6500 kg in Pool 3 to ~417,000 kg in Pool 13. Similar data are unavailable for recent harvest in the MMR and LMR; however, for those years with comparable data (1954–1976), total landings were within the range of harvest in the UMR (Risotto & Turner, 1985).

Despite substantial spatiotemporal variation in harvest, the dominant species in the commercial catch of the MSR have remained fairly consistent. Specifically, common carp, buffalo species, freshwater drum and ictalurids (primarily channel catfish) have dominated the commercial fishery. In the UMR, these taxa comprised 79–93% of the total catch between 1894 and 1922, and 84–94% between 2000 and 2006. Nevertheless, the proportion of ictalurids has declined during the last 30 years, largely due to consumer concerns about contaminants and the development of aquaculture (Krogman *et al.*, 2011). Commercial harvest of fish during the last 120 years has largely focused on the flesh market; however, harvest of roe in the basin has increased substantially during the past 8–10 years. In particular, harvest of shovelnose sturgeon, paddlefish and bowfin has increased 10-fold in some portions of the system and spurred research focused on the effects of harvest on population dynamics and the sustainability of fisheries (e.g. Columbo *et al.*, 2007; Koch *et al.*, 2009).

Similar to subsistence and commercial fisheries, the MSR has long provided a diverse and productive recreational fishery. Records of recreational angling in the MSR date to as early as the 1840s (Carlander, 1954). Currently, the system supports a number of recreational fisheries, but most are in the upper reaches. Recreational fisheries in the HW reach

are intensively monitored by the Minnesota Department of Natural Resources, and most statistics (e.g. angler effort, catch rate, mean length) indicate stable fisheries with low overall effort (Sledge, 1998). The most popular sport fishes in the HW reach include northern pike, smallmouth bass, walleye, channel catfish and panfishes. Popular sport fishes in the UMR include those popular in the HW with the addition of moronids, freshwater drum, sauger and flathead catfish. The recreational fishery of the MMR and LMR has not been extensively monitored. Recreational fisheries in the lower river are less diverse than in upstream reaches due to the general lack of coolwater species that are abundant in the HW and UMR (e.g. smallmouth bass, northern pike, walleye). Important recreational fisheries in the MMR and LMR are dominated by ictalurids and largemouth bass.

Unlike other systems in the mid-western USA where subsistence, commercial and recreational fisheries are often in conflict (e.g. Beard *et al.*, 2003), competition among fisheries in the MSR is low. Catfish fisheries represent an important exception. For example, in Pools 9–19 of the UMR, total commercial harvest of catfishes (primarily channel catfish) showed a significant decline of ~8600 kg year^{-1} between 1955 and 1985 (Pitlo, 1997). The decline was thought to be the result of recruitment overfishing by commercial harvesters. Following an increase in the minimum length of fish that could be harvested (i.e. implemented in 1985), catch rates of age-0 channel catfish and total yield in the commercial catch increased significantly. Increased abundance and larger size structure of channel catfish in the system had an influence on the recreational fishery; channel catfish went from the sixth most abundant species in the creel in 1963 to second in 1994. While some direct and indirect competition undoubtedly occurs between different fisheries in the MSR, the greatest threats to the fisheries are changes in habitat conditions and the introduction of invasive species. The recent invasion of bighead carp and silver carp, particularly to the MMR, LMR and large tributaries, is a serious threat to the entire ecosystem. Unfortunately, the effects of Asian carp are only beginning to emerge, but deleterious effects on native fish populations and fisheries have already been dramatic in some areas (Sampson *et al.*, 2009). Nonetheless, Asian carp also provide potential opportunities for commercial harvest if markets can be established. An Asian carp processing plant opened in 2014 southern Illinois with the intention of exporting 'clean' Asian carp from the Mississippi River to Asia where such fish are desirable, but where local Asian carp populations have high contaminant burdens. However,

the plant is temporarily shut down due to the emission of 'unpleasant odours'. Efforts to develop local markets for Asian carp in North America include carp cook-offs and working with chefs to increase the appeal for carp flesh.

The MSR system has long provided important fishery resources. While the various fisheries have not been in a state of conflict, future stressors to the system suggest that minimising habitat degradation and the effects of invasive species will be critical for continued coexistence of subsistence, commercial and recreational fisheries in the MSR.

15.3.3 The Colombian Amazon fishery

The Colombian Amazon has an area of ca. 480,000 km² corresponding to 42% of the National Territory and over 6% of the entire Amazon Basin (UNEP & ACTO, 2009). It is the largest border of the country with a population of about 900,000 people, of which 9% belong to one of 56 ethnic groups (Gutierrez *et al.*, 2004).

Tropical freshwater ecosystems are extremely dynamic and maintain a diverse structural complexity. Large river-level fluctuations affect environmental conditions on a more or less annual cycle, causing habitats and species to change on a seasonal basis (Junk, 1997). These changes in water levels and the transitions from an aquatic to a terrestrial phase not only create and destroy a series of heterogeneous aquatic habitats, but are the key to maintaining important levels of aquatic biodiversity expressed in complex food webs. So far, 753 fish species have been identified in the region (Agudelo *et al.*, 2011), positioning it as the richest region in the country.

Dependence on fishing is substantial and, arguably, the most important activity supporting local and regional livelihoods and economies along the Amazon River. Fishing supports the livelihoods of around 1000 Colombian families along the Amazon River (Amazonian Trapezium located in the south of the Colombian Amazon region) and a minority of these families supply the national fish market with 8600 tonnes per year, representing 37% of total freshwater fish production in Colombia. According to Riaño-Umbarila (2003), fishing is part of the local people's daily routines. Fishing gives people the chance to bring food to their families. The remainder is sold and the money is used to buy basic goods and supplies.

Four types of fisheries take place in the region (Portocarrero-Aya, 2012). Catch-and-release recreational angling takes place mainly during August

and September when water levels are low. The complexity of habitats provides a variety of desirable species for anglers from all over Colombia and the world. Recreational fisheries provide only a small part of the income for tourist agencies and guides, primarily in and around Leticia and Bogota, although the area has high potential for supporting recreational fisheries (Agreda-Rudenko, 2008). There are no clear regulations related to the catch-and-release of fishes and the country requires implementation of a code of practice to regulate any expansion of such fisheries.

Subsistence fisheries are probably the most visible service provided by freshwater ecosystems in the region. Heterogeneity in aquatic habitats contributes to high production of fishes, which is reflected in the contribution of fishes as a major source of protein to local communities in areas south of the Colombian Trapezium (88 species; 100–500 g day^{-1}; Fabre & Alonso, 1998; Agudelo *et al.*, 2011). Dependency on the river and its fishery resources makes the human inhabitants vulnerable to changes in the fish species composition and to changes to freshwater habitats. According to Ochoa *et al.* (2006), institutional data on the intensity of subsistence fishing is absent and, therefore, there are no statistical data showing local aspects such as the amount of fish extracted and traded, or the amount of fishing effort imposed on the resource. However, something is known about the species preferred by locals; selection depends on availability, taste and cultural preferences. Species like palometa (*Mylossoma duriventre*), bocachico (*Prochilodus* spp.), yaraqui (*Semaprochilodus* spp.), sabalo (*Brycons* spp.), piranha (*Serrasalmus* spp.), paco (*Piaractus brachypomus*) and gamitana (*Colossoma macropomum*) constitute the main diet of the local residents (Agudelo, 2007). In the region, all fisheries are artisanal, and subsistence fishing predominates over commercial fishing (Ochoa *et al.*, 2006).

Commercial fishing has supported the local and national economy since 1938, when the arrival of 'cold rooms' (to store fish fresh) and airlines were available to accommodate the supply of Amazonian fish to the large cities of Colombia (Salinas, 1994; Agudelo *et al.*, 2011). Around 95% of the fish traded in Leticia (the Amazonian capital) is shipped, either frozen or dried, by plane to Bogota, where 67% is consumed; the remainder supplies other fish markets in Colombia (Ochoa *et al.*, 2006). According to Ochoa *et al.* (2006), the demand for Amazonian fish has increased 155% from 1977 to 2002. Management of commercial fishing is complex because the fisheries include multiple species harvested using a variety of gears that vary in space and time (as a response to changes in the river level), and include diverse social, cultural and

economic dynamics. Either way, an ecosystem approach is important for the management of migratory species, especially those representative of the regional fisheries because threats to the fisheries are limited to the effects of fishing. For instance, logging in the headwaters and the floodplain alters habitats that serve as refuge areas, nursery habitats and foraging areas for predators. Mining, an increasing activity in the Putumayo and Caquetá rivers, affects and pollutes the streams used as migratory and spawning corridors for migratory fishes.

Ornamental fisheries are those where fishes are harvested for the ornamental aquaculture trade. Although they may be considered as a subset of commercial fisheries, they constitute an important income to local fishers and traders. In 2009, approximately 2.2 million individual fishes representing 41 species were sold (Ajiaco-Martinez *et al.*, 2012). The city of Leticia is the most important port of collection and export of ornamental fishes, contributing 86% of the total production of the Colombian Amazon (Portocarrero-Aya, 2012). However, a comprehensive understanding of ornamental fisheries remains poor (Agudelo *et al.*, 2011).

Currently, Colombia does not have either a defined policy on fisheries and aquaculture development or strategic guidelines to manage artisanal fisheries. For the Amazon region, only a few regulations banning fishing at certain times or fishing gears, minimum capture sizes, and restricted fishing areas have been expedited. Legal frameworks do not match the social, economic and environmental dynamics of this complex region, and the low budgets assigned to implement management strategies means little can be done to manage the fisheries effectively. Improvements in the institutional structure and increased financial support of the fishing authorities in the region are vital for the survival of the activity and to ensure that inland fisheries are sustainable (Portocarrero-Aya, 2012).

15.3.4 Lower Mekong River fisheries

The Mekong is the longest river in Southeast Asia. It runs for approximately 4800 km from its source on the Tibetan plateau through China, Myanmar, Lao PDR, Thailand, Cambodia and Vietnam to the South China Sea, where it discharges on average 475,000 million m^3 per year. The total Mekong Basin catchment covers an area of 795,000 km^2 and has about 73 million inhabitants. The Lower Mekong Basin (LMB) comprises the four countries – Cambodia, Lao PDR, Thailand and Viet

Nam – and covers 77% of the total basin, with some 55 million people. The Mekong River Basin hosts one of the most diverse freshwater faunas in the world. There are 1200 recorded fish species.

The capture fisheries of the LMB have a centuries-long history of catch technology, local resource knowledge, fish processing, marketing and social organisation (Sverdrup-Jensen, 2002). Much of the fishing technologies are indigenous to the Basin or have been extensively adapted to local conditions, and are manufactured with extensive use of local materials. Most fisheries activities are based on an intimate knowledge of fishes' responses to seasonal environmental changes.

The Mekong fisheries range from individual seasonal fishers in the highlands of Lao PDR to fishing lot owners with large-scale commercial operations in the Great Lake (Tonle Sap) of Cambodia or certain areas of the mainstem rivers; and from full-time specialised traditional fishers in the Khone Falls area to unemployed people in villages in Northeast Thailand who fish to support themselves in times of economic difficulties. The highest degree of commercial specialisation is found in the large floodplains of central and southern Cambodia and the northern part of the Mekong Delta. Large-scale fishing operations are often based on exclusive access to sites obtained through purchase of government licences, although this system is being disbanded in Cambodia and could affect the intensity of fishing and result in social disruption. Throughout the LMB at least 40 million rural dwellers are estimated to be active in the fishery.

All Mekong fisheries are highly seasonal and largely determined by the river flood-pulse from June to October (Poulson *et al.*, 2002). Catches comprise whitefish species during their migration when the water level rises following the onset of the monsoon rains. In the dry season, catches are mainly taken in or around deeper stretches of rivers where many sedentary and migratory fish species take shelter. Seasonal peaks result in a glut of fresh fish far beyond what local demand can absorb. This has stimulated the development of highly effective, low-technology fish processing and marketing systems based on the production of fermented fish products, pastes and sauces. This large, mainly domestic, industry provides seasonal employment and spreads the nutrition and economic benefits of seasonal fish production over the full year.

In addition, there are numerous small-scale fisheries operating in the LMB (Sverdrup-Jensen, 2002). In all four countries of the LMB, monofilament gillnets with their different ways of operation (floating, set, bottom, surface or mid-water) are the most popular gear. A great diversity of basket traps made of widely available natural raw materials, such

as bamboo, rattan and vines, adapted to the needs of fishing–farming households, are also used throughout the LMB. In the uplands of the Lao PDR, northern Thailand, northeast Cambodia and the central highlands in Vietnam, mainly small-scale fishing gears, including fishing by hand, are used to retrieve aquatic animals from the wetlands, including rice fields.

Estimates of the total catch from the fisheries in the LMB have increased dramatically in recent years and exceed 2.6 million tonnes annually with a value exceeding US$1.7 billion. These figures are based on per-capita consumption of all freshwater fish and other aquatic animal products, but exclude the fish produced in aquaculture and in reservoirs (respectively, 260,000 and 240,000 tonnes; Coates, 2002).

The Mekong is threatened by a range of human activities, including agricultural development (especially for rice), deforestation, urban development flood control, alien invasive species and dam development. Some 25,000 reservoirs have been constructed in the LMB, mostly for irrigation, but in recent years there has been a resurgence of interest to promote hydropower. In particular, 11 large dams are proposed on the mainstem. Existing reservoirs have interfered with the migration of fishes to the point where some species have disappeared and it is estimated that between 1.2 and 1.5 million tonnes of fish yield will be lost if the mainstem dams are constructed (Dugan *et al.*, 2010).

15.3.5 Lower Fraser River Pacific salmon fisheries

The Fraser River is one of Canada's largest rivers (drainage area = 217,000 km^2). Starting in the Rocky Mountains, the Fraser River flows for 1370 km before it discharges into the Strait of Georgia near the city of Vancouver, British Columbia (Thompson, 1981). For at least ten millennia the Fraser River Basin has been home to indigenous groups (in BC called First Nations) who depend on the river for subsistence, as well as cultural and spiritual activities. Today, the lower reaches of the Fraser River and its tributaries are highly altered with evidence of fish population declines (e.g. McDaniels *et al.*, 2010; Martins *et al.*, 2011). The Fraser River watershed is home to more than 100 genetically and geographically distinct populations of Pacific salmon, and supports multisector, multispecies fisheries that have great economic, cultural, social and political significance.

Three fishing sectors – commercial, recreational and subsistence (locally called First Nations (FN)) – co-occur, and target adult Pacific

salmon during their upriver return migration from the ocean to spawning grounds. Five Pacific salmon species are present in the Fraser River: pink (*Oncorhynchus gorbuscha*), sockeye (*O. nerka*), chinook (*O. tshawytscha*), chum (*O. keta*) and coho salmon (*O. kisutch*) (Williams, 2007). The three fishing sectors are managed by the Department of Fisheries and Oceans Canada (DFO) with the exception of the marine commercial fishery, which has joint management with the Fraser River Panel and the USA. Most inland fisheries are concentrated in the lower Fraser River, with the upper reaches accessible only to FN communities. As such, we focus our case study on the lower Fraser River and its multisector sockeye salmon fishery.

The FN fisheries generally operate on a small scale, using primarily beach seines and gill nets. The fishing sector involves over 72 FN bands who have the legal right to fish for food, social and ceremonial (FSC) purposes with priority to harvest allocations and access over the recreational and commercial fisheries, subject only to conservation needs (English *et al.*, 2011; Cohen, 2012). The FN fishing sector has been considered a subsistence fishery; however, since 2004, 'economic opportunity' fisheries have been negotiated with lower Fraser River FN allowing the fishers to operate commercially under negotiated allocations and catch monitoring procedures. In 2010–11, a total of 379 communal aboriginal commercial licences were issued for salmon. The average harvest rate (2001–09) for the FN fishing sector resulted in just over 700,000 Fraser sockeye harvested annually (35% of total harvest across all fishing sectors), which included catches from the FSC (29%) and the FN commercial fisheries (6%) (reviewed by English *et al.*, 2011).

The Fraser River supports a substantial recreational fishery that directly overlaps and coexists with the FN fishing sector. Not surprisingly, this has resulted in some conflict and animosity. In 1991, a directed recreational fishery on sockeye salmon in the lower Fraser River opened (Roscoe & Pollen, 2010) with fewer than 10,000 sockeye captured and harvested. By 2002, the fishery grew rapidly and catches were estimated to be more than 100,000. From 2001 to 2009, the average annual catch of Fraser River sockeye salmon by recreational anglers accounted for 3% of the total sockeye salmon harvested (average of ~60,000 sockeye salmon; reviewed in English *et al.*, 2011).

The commercial fishery is a competitive, limited-entry fishery using gillnets, seines and troll gear. The fisheries are managed using time and area closures, as well as individual harvest quotas. Catches are monitored using 'sales slip', log books, observers on deck and in-season reporting

systems. Historically, the Fraser River sockeye salmon commercial fishing sector operated only in marine waters and in the tidal portion of the Fraser River; however, with the introduction of FN economic opportunity fisheries, commercial fishing now also occurs in-river.

Conservation is the first priority for fisheries management of the lower Fraser River salmon fisheries. The fisheries are managed with the objective of reaching escapement targets and allowing a proportion of the run to be harvested. In 1998, DFO introduced a selective fishing policy applied to all fishing sectors that aimed to minimise or avoid the harvest of species and stocks of conservation concern (i.e. by-catch) as part of developing responsible fisheries. As such, all fishing sectors are subjected to time and area closures, mandatory live release of non-target species, and gear and technique modifications (e.g. minimum mesh size and shortened net sets for gillnetters, barbless hooks for recreational fishing, brailing for seiners). Some incentives have been initiated for commercial fishers by granting priority fish allocations to vessels instigating selective fishing over traditional commercial fisheries.

Issues and conflict among the three fishing sectors generally surround the 'intersectoral allocations'. Harvest allocation for salmon is the priority for First Nations FSC purposes. Once conservation and the FN FSC needs are met, then allocations are granted to recreational and commercial sectors, but are not guaranteed. As a result, feelings of inequality and unfairness can arise from those sectors with lower priority. The recreational fishing sector is granted a maximum average of 5% of the combined recreational and commercial sockeye salmon harvest resulting in tension between the two sectors as the recreational fishing sector continues to grow (Cohen, 2012). Furthermore, commercial FN fish allocations are negotiated on the premise of balancing the objective of supporting the economic development of FN communities and the interests of all fishery participants. Evidently, the disparities of harvest allocations can create conflict and tension amongst the different fishing sectors.

The DFO is moving towards a 'shared stewardship' management strategy to promote collaboration, participatory decision-making, and shared accountability and responsibility among the fishing sectors and management. In attempts to facilitate communication among all fishing sectors, the DFO produced an Integrated Fisheries Management Plan (IFMP) to provide a planning framework for the conservation and sustainable use of fisheries resources. It incorporates the results of consultations and input from the FN, recreational and commercial advisors

as well as other interest groups in the hope of coordinating fishing plans and resolving potential issues amongst the sectors (Cohen, 2012). Continual effort is being made to engage First Nations and stakeholders to participate in co-management.

Despite the complexity of the salmon fisheries in the Fraser River, habitat alterations, changes to hydrological regimes and warming river temperatures play major roles in the declines of salmon populations (e.g. Martins *et al.*, 2011). Fisheries interact with these environmental changes by causing additional physiological stress on live-released non-target fishes, which can result in unobserved mortality or potential in behavioural impairment such as spawning (e.g. Baker & Schindler, 2009; Gale *et al.*, 2011). The issues and conflicts identified here extend downstream into the ocean, resulting in a strong need for management to not only consider the multisector, multispecies of the Fraser River salmon fishery, but also connecting the multienvironments and stressors affecting salmon and the fisheries.

15.3.6 Eel fisheries of Europe

The panmictic (Dannewitz *et al.*, 2005) European eel population (*Anguilla anguilla*) is under threat (International Council for the Exploration of the Sea, 2010). Current recruitment levels are less than 1% of the maximum historic record (Dekker, 2008, 2009; International Council for the Exploration of the Sea, 2010). The eel decline is negatively affecting many small-scale European inland fisheries (Feunteun, 2002; Dekker, 2008; Dorow *et al.*, 2010), because both commercial and recreational fisheries intensively harvest and compete for the resource. However, the eel is not an important fisheries resource in all European countries due to different customs in consuming the species. In addition, different life stages are sought and harvested in different countries.

Managing eel is technically difficult due to the complex life cycle of the species and the multiple nations and fisheries that exploit it throughout Europe. The species transcends freshwater and marine environments and is thus affected by multiple continental and oceanic factors, none of which are under full control of one country or management agency. Moreover, because important sources of eel mortality in the marine environment appear to include the effect of changing nutrient conditions in the spawning grounds and climate change (Knights, 2003; Friedland *et al.*, 2007), there are no local, regional, or national solutions to the problem of the rapidly diminishing eel stock. International

collaboration is needed to halt the eel decline, which is particularly hard to organise politically.

Impacts on eel vary across marine and freshwater environments. As mentioned, changing nutrient conditions and altered oceanographic currents likely impact recruitment in the marine environment. In freshwater, the eel is affected by exploitation of the different life stages by commercial and recreational fishing, pollution, predation by piscivorous birds, parasites (especially the introduced nematode *Anguillicola crassus*), and habitat alterations due to hydropower activities and dams (Feunteun, 2002; Starkie, 2003; Dekker, 2009). Uncertainty about the causes of the eel decline pose a significant challenge for identifying effective interventions to conserve this species and hamper stakeholder buy-in and commitment to conservation (Dorow & Arlinghaus, 2012).

A range of political and management actions have been initiated to conserve the eel population. The species has, for example, been red-listed as critically endangered by the International Union for the Conservation of Nature (Freyhof & Kottelat, 2008). In 2007, the European Union (EU) released the so-called eel regulation (EU Council Regulation 1100/2007), requiring member states to develop eel management plans at a river basin scale by the end of 2008 to safeguard a 40% escapement rate (European Commission, 2007). Since then, States whose management plans are not approved or fail to meet targets face immediate reductions in total eel fishing effort by at least 50% or implementation of other measures to reduce eel harvests by 50% (European Commission, 2007). While from a biological perspective the effectiveness of effort control measures is as uncertain as our understanding of the causes of decline, a 50% reduction in fishing mortality would have significant socioeconomic impacts on recreational and commercial eel fisheries across much of Europe (Dekker, 2008; Dorow *et al.*, 2010). Moreover, because the contribution of eel mortality by fishing to the current degraded state is uncertain, some states are reluctant to implement management actions that affect fisheries negatively, instead focusing on alternative actions such as elevated stocking of glass eels into freshwater ecosystems.

Commercial and recreational fisheries can exert substantial fishing mortality on eel (Dekker, 2008, 2009). Fishing-induced mortality may be reduced by directly restricting harvest rates of captured fish (e.g. by implementing a maximum size limit for eel to allow migration to the ocean) or by reducing fishing effort, or indirectly as a response to altered harvest regulations (Beardmore *et al.*, 2011). Direct regulation of

effort includes diverse regulations as permit lotteries or spatiotemporal closures. Certain regulatory policies combine these mechanisms to compound their intended conservation benefits. Any drastic regulation of eel fishing, both commercial and recreational, will be accompanied by outright social conflict and result in welfare consequences of many million € per year across Europe (Dorow *et al.*, 2010). Despite the many possible ways by which eel fishing could be regulated, it is currently unclear how management of eel fishing using traditional harvest regulations would help conserve the eel stock. This is because multiple factors other than fishing influence eel populations. Hence, the benefits of increased escapement due to more restrictive eel harvest on the long-term status of eel stocks remain questionable. Overall, the ability of eel management plans using freshwater conservation strategies to meet EU targets for eel fisheries remains largely unknown, *inter alia* because the bottleneck for the freshwater eel population may lie in the marine environment.

15.3.7 Tigerfish in the Zambezi River of Central Africa

The complex riverine, floodplain and lacustrine environments of the Zambezi River system support multigear subsistence and commercial fisheries. Recreational angling is of lesser importance in most water bodies, where food production is of higher importance. In the Zambezi River channels and man-made lakes, however, one of the world's premier freshwater angling species, the tigerfish, *Hydrocynus vittatus* (world record = 16.1 kg; IGFA, 2012), is a major attraction. A variety of large, uniquely endemic cichlid species add to the attraction of angling in these areas.

The upper Zambezi comprises the area upstream of the Victoria Falls and the river is bordered by four countries: Zambia, Zimbabwe, Botswana and Namibia. Over a 120-km extensive floodplain area, known in Namibia as the Caprivi Floodplains, the river forms the Namibia–Zambia border. Recreational catches have only been assessed in the Namibian sector, where catch records of five local angling lodges in Caprivi show that in 2010 some 4000 visitors caught and released in the region of 38,000 tigerfish and 14,000 cichlids. These riverside lodges are dependent on angling tourists for up to 70% of their revenue and in remote, rural floodplain areas, lodges are often the only source of paid employment and are therefore of major local economic importance (Sweeney *et al.*, 2010).

Historically, recreational anglers and the artisanal fisheries were spatially separated to some extent. Recreational angling focused mainly on the main river channels while artisanal and subsistence fishers set their gear, mainly gillnets and fish traps, in backwaters and on the floodplain. In the last two decades, however, improved communications, together with rapidly increasing human populations, has led to the commercialisation of the previously subsistence fisheries. A huge demand for fish in major Zambian urban centres and also in the neighbouring Democratic Republic of Congo put Zambian fisheries under extreme pressure. Migrant fishers, with no interest in long-term sustainability, encroached into Namibian waters where they began to compete with local fishers, creating severe problems for local communities for whom food security from fishing is a vital livelihoods component. An estimated total annual fish yield from the Caprivi Floodplains (excluding the highly productive but ephemeral Lake Liambezi) of approximately 5000 t in 2011 (Tweddle & Hay, 2011a) is indicative of both local dependence on the fishes and the scale of commercial exploitation. The larger, more valuable species were severely depleted through excessive fishing effort and the use of destructive fishing gears such as shore seines and drifting gillnets. The situation deteriorated to the point where larger species were depleted to such an extent that fishers reduced their mesh sizes to target smaller species as well as the juveniles of the larger species.

The increasing effort created two problems for the angling tourism industry. (1) Trophy tigerfish (> 5 kg) and cichlids (> 2.5 kg) were becoming scarcer, and (2) the visual impact of commercial fishing using gillnets was leading to perceptions by tourists that the upper Zambezi River was being overfished. This was beginning to have significant impacts on the tourist industry, with some lodges losing some of their regular customers. The subsistence fishing communities in Caprivi also suffered from the declining fish stocks. The twin assaults on food security for local communities and the tourism angling resource stimulated the development of co-management arrangements between angling lodges, recreational angling club and the local fishing community.

The concept of conservancies has taken root in Namibia (NACSO, 2010, 2011), with much of the Caprivi Floodplain now under recently established (2005–2009) or planned conservancies. These community organisations are supported by government legislation and are successfully assuming responsibility for the management of wildlife and other natural resources. The concept is now being expanded to protect the fish stocks from excessive exploitation. Supported by a Ministry of Fisheries

and Marine Resources (MFMR) project, conservancies established fisheries committees to manage the resources for the communities' benefit. The idea of Fish Protection Areas (FPAs), analogous to Marine Protected Areas (MPAs), was adopted. While the major aim of such areas is to act as protected breeding areas for the most important species (food fishers and anglers target the same large cichlids and tigerfish), the conservancies saw extra potential benefits in the form of earning revenue from anglers by allowing the use of non-consumptive catch-and-release angling on payment of fees.

Two pilot FPAs have been established and are functional (Tweddle & Hay, 2011b). In the first, an 11-km long side channel in Sikunga Conservancy, strong support has been forthcoming from lodges and the Nwanyi Angling Club in Katima Mulilo, organiser of the Zambezi Classic Tournament. The second pilot FPA in Impalila Conservancy is the 13-km long Kasaya Channel that links the Zambezi and Chobe Rivers creating Impalila Island. Lodges in the rapidly growing town of Kasane in Botswana on the edge of Chobe National Park and also on the opposite Namibian bank offer angling as a major tourist activity, increasingly based on flyfishing for tigerfish. Conflicts occur between tourist interests and highly commercialised illegal netting in areas adjacent to the FPA. It is in the long-term interests of the local economy that these issues are resolved through negotiated agreements between conservancies and the tourism industry to expand the FPA to accommodate the prime tigerfish angling zone, while ensuring that fees from tourist angling compensate the conservancies for the loss of fishing areas.

In the region, the conflict between commercialisation of the food fishery and tourism is not restricted to the Upper Zambezi. The neighbouring Okavango River system is a major tourism destination and thus foreign exchange earner for Namibia and Botswana, particularly in the world-renowned Okavango Delta, established (in 2014) as a World Heritage Site. In the narrower, northern part of the delta, known as the Panhandle, commercial fishing was developed through government subsidy in the early 1980s (Nengu, 1995). Since that time, there has been intermittent conflict between commercial fishers and the tourism industry (Tweddle *et al.*, 2003; Mosepele & Ngwenya, 2010). The concept of establishing FPAs for the benefit of all stakeholders may be an alternative approach to the either/or zonation currently promoted. Expectations for direct revenue earning from FPAs need to be managed as there is a limit to potential revenue in areas remote from angling tourism lodges. Emphasis in the Namibian MFMR project activities is

on the importance of the FPAs to counter severe overexploitation of the most valuable fish species driven by unsustainable commercial demand

15.3.8 Mahseer in the Western Ghats region of India

The rivers of the Western Ghats, which are exceptional hotspots of freshwater fish diversity and endemism, support poorly known commercial, recreational and subsistence fisheries. High human population density (300–350 individuals km^{-2}; Molur *et al.*, 2011), including the presence of several marginalised tribes and forest-dwelling communities, and their congregation along the banks of major river systems has resulted in a high dependence on freshwater fishes for both food and income. Freshwater commercial and subsistence fisheries in the Western Ghats are primarily small-scale fisheries. There is also a small but significant fishery for endemic (and mostly threatened) aquarium fishes, and a recreational fishery for large cyprinids. These fisheries are *de facto* open access. Exceptions include protected areas, where there are licensed fishing agreements for food fishes, and a prohibition for both aquarium and recreational fisheries.

Decades of unmanaged harvest has led to severe population declines of large food fish species and the precarious state of fisheries in many rivers and reservoirs of the region. A decrease in both the size and abundance of the commercially important species has also resulted in fishers using destructive techniques such as poisoning and explosives to maintain their capture rates (Molur *et al.*, 2011). The large-scale mortality encountered during such fishing, and its biological consequences, has greatly reduced the numbers of small fishes otherwise available to aquarium fish collectors, and larger juveniles and adults harvested as food.

One of the main targets of food, aquarium and recreational fishers is the mahseer, represented by three endangered species, *Tor khudree*, *T. malabaricus* and *T. mussullah*. While medium-sized mahseer are targeted for food, smaller juveniles are collected for the aquarium trade and large adults are the choice for recreational anglers. Intensive harvest of these species, mainly for food, has resulted in population reductions of more than 50% in the last 10 years, and several local fisheries are under a threat of imminent collapse (Raghavan, 2011; Raghavan & Ali, 2011; Raghavan *et al.*, 2011).

The Cauvery is the only river in the Western Ghats where all three forms of fisheries (commercial, subsistence and recreational) coexist. The river is globally renowned for its mahseer recreational fishery (Anon.,

2012a). In the mid 1970s, several stretches of the Cauvery were leased by a local non-governmental organisation (NGO), the Wildlife Association of South India (WASI). This was to control both indiscriminate fishing (outside the protected areas) and poaching (inside protected areas) by migrant settlers who often used explosives and other destructive techniques. Apart from regular stocking of mahseer fingerlings, WASI set up small, seasonal fishing camps in the river to promote responsible 'catch-and-release' angling. The success of WASI encouraged the establishment of four full-time angling camps in the 1980s along the Cauvery to promote fish-based ecotourism and angling. The revenue obtained from these camps helped to control illegal fishing through the establishment of anti-poaching camps and patrols, as well as rehabilitation of former poachers as fishing guides.

Towards the end of 2012, the Government of India decided to expand the size of a protected area near the fishing camps. This expansion led to the closure of all camps and a ban on recreational angling because 'fishing' is considered equivalent to 'hunting', and the latter is prohibited inside protected areas as per the Wildlife Protection Act of India. This move will no doubt negatively impact populations of the endangered mahseer, as wildlife managers and government officials in the region lack resources to efficiently manage illegal fishing (Anon., 2012b). This is because even licensed fisheries inside several protected areas of the Western Ghats are poorly managed (Raghavan *et al.*, 2011).

The Cauvery fishing camps were also involved in feeding several thousand kilograms of cereals to keep mahseer within the protected stretches of river. The loss of supplemental feeding will likely result in fish migrating to areas outside the protected area where fishing is open-access and often destructive in nature. The recreational angling community believes that without anglers and the annual revenue that the sector provides for anti-poaching patrols and camps, the Cauvery mahseer will be exposed to illegal fishers and poaching gangs. Also, several local people including former poachers, who earned an income from recreational fisheries, could revert to their old profession to sustain livelihoods (Anon., 2012b). This could prove disastrous to both the endangered mahseer and the overall ecosystem health of Western Ghats' rivers.

In general, the role of freshwater fish as 'wildlife' is somewhat anomalous in India, as none of the primary wildlife conservation legislation in the country focuses on the conservation of freshwater fishes. Freshwater fishes are viewed as an open-access resource and a free commodity that

can be harvested from nature. Legislation concerning conservation, management and sustainable use of freshwater fishes needs to be redefined to ensure a better future for inland fisheries in the Western Ghats and India.

15.4 SYNTHESIS

These case studies highlight regional variation in inland fisheries activities. Beyond painting a picture of the global diversity of inland fisheries, a goal of adopting the case study approach was to identify the common challenges and opportunities that exist with the sustainable exploitation of inland fisheries. Here we provide a synthesis to identify common issues, threats, opportunities and solutions, presented here as a series of recurring themes.

15.4.1 Freshwater fisheries sustain livelihoods

One of the patterns emerging from all of the case studies was that freshwater fisheries sustain livelihoods and generate significant socio-economic benefits. In some regions, the harvested fish contribute essential protein, which is critical for food security. In addition, even in areas where subsistence fisheries are critical, small-scale commercial fisheries, and increasingly the recreational sector, generate wealth that enables fishers (and others, such as those active in the tourism industry) to have the resources needed to sustain their families. In developed nations, recreational and commercial fisheries also generate considerable income that provides direct and indirect employment. In addition, subsistence fisheries in developed countries, which are often associated with aboriginal communities, are of significant cultural value and provide food for ceremonial purposes and sustenance. If freshwater fisheries were to be severely restricted (especially due to conservation concerns arising from other threats) or if they are poorly managed, the consequences could be severe. Unfortunately, a lack of high-quality information makes it difficult to quantify the true value of inland fisheries (Arlinghaus *et al.*, 2002; Beard *et al.*, 2011; World Bank, 2012), which potentially places all three fishing sectors and the livelihoods of millions of people at risk.

15.4.2 Change and adaptation are the norm

Evident in nearly all of the case studies is that the fisheries are not static and there has been a number of changes to which the fishers and

managers have to respond. For example, the introduction of non-native fishes, either intentionally (e.g. Pacific salmon in the Laurentian Great Lakes) or unintentionally (e.g. Asian carp in the Mississippi River), has led to both problems and opportunities that have required adaptation by fishers and managers (Chapter 8). Pacific salmon create many recreational fishing opportunities in the Great Lakes, while simultaneously acting as a biological control of the invasive alewife. At the same time, the economic importance of the recreational fishery for Pacific salmon means that fishery managers can choose to manage for a biomass of alewife that may impede efforts to rehabilitate or reintroduce lake trout and Atlantic salmon populations (Dettmers *et al.*, 2012). In the Mississippi River, commercial fishers are beginning to exploit invasive Asian carp as markets begin to develop. In many locales, commercial fisheries in inland waters are declining while recreational fisheries are expanding. This is particularly the case in emerging economies like India (see mahseer case study) and Brazil and South Africa. Additionally, the increasing concern about climate change on Pacific salmon in the Fraser River and European eel will also call for fishers and fisheries managers to adapt fishing practices and consider the additional effects of fisheries on fish populations. Although stock assessment and harvest monitoring are essential for documenting changes and developing appropriate responses, some of the solutions to the issues identified lie way outside the fisheries sector and are thus difficult to be addressed by fisheries management alone (e.g. climate change).

15.4.3 Connectivity is critical

Freshwater fisheries are inherently connected to their surroundings, especially in a watershed context. For example, the Great Lakes Basin fisheries are intrinsically linked to the 30 million people living on the shores of the Great Lakes and their associated activities (see stressors below). Similarly, some of the discussed freshwater resources, such as eel, transcend boundaries among nations and among freshwater and marine environments. Inland fisheries are also thought of in terms of longitudinal connectivity, considering the role of barriers on fish movement as well as connections between freshwater and marine systems. Diadromous species (e.g. European eel case study, Fraser River case study) require holistic management plans that cover the entire life cycle and migration extent (Chapter 11). Less attention, however, is given to lateral connectivity and the importance of the floodplain to fishery

production and biodiversity. Maintaining the links with the floodplain is critical given the propensity to channelise rivers (see Mississippi case study) and the importance of floodplains to fishery production globally (e.g. Mekong, Zambezi and Amazon).

15.4.4 Multiple, complex and interacting stressors create challenges

A consistent aspect is the recognition that there are multiple, complex and often interacting stressors that threaten inland fisheries, most of which are external to the fisheries themselves. Unlike marine fisheries, where fisheries exploitation is the primary threat, inland fisheries face a suite of stressors associated with, among others, urbanisation, agriculture, hydropower and industry, which collectively have led to degraded habitats, reductions in water quality, alterations in flows, and loss of connectivity (e.g. Mississippi, Mekong and European eel case study; Arlinghaus *et al.*, 2002). Layered on top of such competing uses for water are invasive species and climate change (Chapters 3 and 8). There have been many calls for incorporating fisheries management into a broader conceptual framework of integrated water(shed) management in inland systems (Arlinghaus *et al.*, 2002; Collares-Pereira & Cowx, 2004; Cowx & Portcarrereo, 2011; FAO, 2012).

15.4.5 Conflict among sectors is common

There are many examples of conflict between recreational and commercial, between subsistence and commercial, and between recreational and subsistence fisheries. In almost all cases, the basis for the conflict is allocation and perceptions of inequitable allocation. In areas with aboriginal peoples (e.g. Fraser River case study), the issues can be particularly salient given the hierarchy of allocation and the primacy of addressing ceremonial needs for First Nations. However, even in the Fraser River, there has been much effort in the last few years for the different sectors to work cooperatively on joint issues. In the Great Lakes Basin, there is conflict between recreational and commercial fisheries, but an inclusive and transparent management process has gone some way to building understanding and alleviating conflict. In the Mississippi River basin, there is little evidence of conflict, mainly due to little competition for the same species (but see the exception with catfish). In the eel case, conflict is severe because the resource is dwindling and both commercial and recreational fisheries compete for the remaining fish. Governance structures that engage all three sectors in a transparent way are likely the best

strategy to reduce intersectoral conflict in inland fisheries (Arlinghaus, 2005; FAO, 2012).

15.4.6 Management across jurisdictions is complex

Nearly all of the case studies represent fisheries that occur across jurisdictions, often multiple states, provinces and countries. For example, the Laurentian Great Lakes basin straddles Canada and the USA, which necessitated a number of bi-national agreements and the formation of the Great Lakes Fishery Commission as well as the International Joint Commission. Similarly, the Fraser River Pacific salmon fisheries in Canada fall under a bi-national agreement with the USA, given joint exploitation in marine waters which had led to the Pacific Salmon Treaty and the formation of the Pacific Salmon Commission. Similar situations exist for European eel (governed in a generic way by the European Commission) and on the lower Mekong River (Mekong River Commission). Although there is inherent political complexity associated with multijurisdiction fisheries, the need to cooperate often promotes the development of strong governance structures. Another inherent component of multijurisdictional governance institutions (i.e. regional fisheries management bodies) is the inclusion of stakeholder groups in decision-making processes, which promotes buy-in and compliance (FAO, 2012).

15.5 ACHIEVING A SUSTAINABLE FUTURE FOR INLAND FISHERIES

It is unclear how many inland fisheries are biologically sustainable and the extent to which they contribute to conservation problems. Despite efforts by the FAO to place greater emphasis on inland fisheries (FAO, 2011), the reality is that subsistence fisheries and recreational fisheries, which are so important in inland waters, are difficult to monitor (Welcomme, 2001; Beard *et al.*, 2011). A prerequisite of sustainability for inland fisheries (actually for all fisheries) is knowing the state of the resource to allocate biomass for harvest (Krueger & Decker, 1999), although it should be recognised that many tropical floodplain fisheries are resilient to exploitation and it is loss of the flood pulse through water resources development schemes that is the major threat to these systems (Welcomme *et al.*, 2010). Until such information is known, we are left with only site-specific information, biased towards larger commercial and recreational fisheries that are of high economic value. What

is clear is that biodiversity in inland systems is in decline as a result o a variety of stressors (Dudgeon *et al.*, 2006), but what is less clear i whether unsustainable fisheries activities are contributing to the decline (Allan *et al.*, 2005).

The case studies represent some of the best monitored systems with rigorous and long-term stock assessment programmes (e.g. Laurentian Great Lakes). In reality, many millions of smaller inland water bodies and water courses around the globe are subject to no or infrequent stock assessment, and it is unlikely the resources will exist to monitor all the small lakes and rivers in a landscape. It is for that reason that alternatives to stock assessment are needed for data-poor situations, including harnessing local knowledge. In Ontario, Canada, a broad-scale, landscape-level approach to both assessment and management has been implemented to provide information on the hundreds of thousands of water bodies using information from only a sample of fisheries (see Lester *et al.*, 2003). Such approaches may have relevance in other regions. Also needed are rapid appraisal methods that can be applied in developing countries where small-scale fisheries are the norm (Prince, 2010; Beard *et al.*, 2011).

Beyond characterising the state and trends in fisheries, it is also important to better value inland fish stocks (Arlinghaus *et al.*, 2002; Cowx *et al.*, 2004). By valuing inland fisheries it is then possible to make trade-offs relative to the many other uses of inland waters (e.g. agriculture, hydropower; see Welcomme *et al.*, 2010). Indeed, doing so can generate the public support and political will needed to make decisions that benefit biodiversity and livelihoods (Beard *et al.*, 2011), although one has to be cognisant that economists will tend to compare direct economic impact (provisioning services) of other sectors with fisheries and the latter will tend to suffer because the supporting, regulating and cultural services delivered by inland fish are difficult to quantify and therefore often remain unvalued (Cowx & Portocarrereo, 2011). In developed countries, it is often possible to quantify the economic impacts and the net economic value (producer and consumer surplus, see Parkkila *et al.*, 2010) of commercial and recreational fisheries and use these values in allocation schemes. In developing countries, and particularly for subsistence fisheries, ascribing value to fisheries is much more difficult given their diffuse nature. Agricultural household surveys that track food consumption may be one of the best ways to identify the value of such fisheries. There can also be cultural and spiritual value (especially with indigenous peoples), which is even more difficult to quantify. Many inland fisheries,

even when commercial, involve local consumption rather than sending inland fish products to export markets, which makes it difficult to track landings. Knowing which inland fisheries products are consumed, and the type of markets in which they are sold or traded, can provide a means to communicate information about sustainable inland fish products to consumers. Sustainable marine seafood awareness campaigns have been somewhat successful, but similar programmes are less common in the inland realm (Cooke *et al.*, 2011), although the Ontario Commercial Fisheries Association is seeking sustainable certification for its fisheries. Such efforts would need to be tied to local markets given that, unlike the marine realm, most inland fisheries products are not exported.

The complexity and uncertainty inherent in decisions about managing water resources require an ecosystem approach that involves stakeholders from all sectors (Beard *et al.*, 2011). An ecosystem approach, which recognises humans as part of the ecosystem, is fundamental (Garcia, 2003). Similarly, rather than thinking about managing fish and fisheries, it is necessary to think about more holistic approaches such as integrated water(shed) management (Heathcote *et al.*, 1998). This is not to say that fisheries management is not important, but instead to recognise that it cannot be done in isolation of the other users and management objectives for a given system (Collares-Pereira & Cowx, 2004). We presented several case studies that provide excellent examples of multijurisdictional, multistakeholder approaches to managing aquatic ecosystems and hope that such examples will become even more common in the future. Engaging the broader public in inland fisheries issues is also needed to achieve the political will to conserve and manage inland fisheries (Cooke *et al.*, 2013).

To achieve a sustainable future for inland fisheries really means, first, addressing a number of critical information gaps (Welcomme *et al.*, 2010; Beard *et al.*, 2011). Rethinking governance structures and management paradigms to better incorporate diverse stakeholder perspectives and approaching water management from a holistic and integrated perspective are needed. Investments in research and management may be costly, but the long-term costs of not having inland fisheries will be disastrous.

15.6 DISCUSSION QUESTIONS

1. What factors lead to shifts in the prominence in different fisheries sectors following industrialisation?

2. How can one strive for sustainable fisheries when no biological assessment data exist?
3. Which management structures are appropriate for multijurisdictional fisheries?
4. Have inland fisheries led to population collapses as have been observed in some marine fisheries?
5. Why do inland fisheries seem to attract less attention than marine fisheries?

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