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Review

Status of aboriginal, commercial and recreational inland fisheries in North America: past, present and future

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Abstract The inland fisheries of North America (i.e. Canada and the United States of America) are diverse in terms of the sectors that harvest fish, the waters fished and the species targeted. Aboriginal fisheries have a long tradition of harvesting fish for food and ceremonial purposes using gears such as dip nets and spears, and targeting species such as suckers (Catostomidae) and upriver migrating salmon (Salmonidae). The commercial sector includes large-scale industrial operations on the Great Lakes and Mississippi River as well as smaller-scale fisheries throughout North America that harvest fish for food or the bait industry. The recreational fishery is the largest sector (millions of participants) and includes everything from specialised catch-and-release fisheries for muskellunge, *Esox masquinongy* Mitchill and black bass (*Micropterus* spp.) to put-and-take fisheries for rainbow trout, *Oncorhynchus mykiss* (Walbaum). All sectors provide substantial socio-economic benefit and regionally can have significant cultural value and yield an important amount of food protein. Using the best available information and a number of assumptions, total harvest for all three sectors in the inland waters of North America was estimated to be >480 000 t yr^{-1}. Nonetheless, there are a number of internal threats that face these fisheries including over-exploitation, bycatch/release mortality as well as external threats such as inter-sectoral conflict, environmental change, water availability, invasive species and habitat alteration. Given that most inland fisheries are managed at the state/provincial level, there is a need to adopt management strategies that are holistic, coordinated and trans-jurisdictional if inland fisheries in North America are to be sustainable in the future. There is also a critical need for information management systems that enable regional data to be scaled up to the national or continental level, which would facilitate the generation of inland fisheries status reports and the monitoring of trends through time. All stakeholders must recognise that while inland fisheries tend to not receive the same attention from the media, public or politicians as marine fisheries, the potential for local and broad-scale irreversible changes exist and need to be identified and addressed if the many ecosystem services that inland fisheries provide are to be maintained.

KEYWORDS: coordinated management, freshwater fisheries, North America, inland waters.

Introduction

To evaluate the threats and opportunities facing fish populations and ensure sustainable management of the world's fisheries, it essential to conduct syntheses of available data and generate status reports. In the marine realm, such reports are common (Wells 2003) and have garnered much public attention as they have identified worrisome trends in the decline of top predators (Myers & Worm 2003; Dulvy *et al.* 2008), a shift to the capture of lower trophic level organisms (Pauly *et al.* 1998) and collapse of marine fish populations (Jackson *et al.*

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2001). Basic status reports are generated annually by the United Nations Food and Agriculture Organization (e.g. FAO State of World Fish and Aquaculture Reports and Year Books) as well as many national or multi-jurisdictional/inter-governmental fisheries management agencies (e.g. Gulf of Mexico Fishery Management Council; International Commission for the Conservation of Atlantic Tunas). From a comparative sense, status reports focused on inland (i.e. freshwater) fisheries are scarce. Only recently have there been attempts to evaluate the global status of inland fisheries (Revenga & Kura 2003; Welcomme *et al.* 2010; 2013). High-profile papers with generic titles (e.g. global trends in world fisheries; Pauly *et al.* 2005) would imply that they consider both marine and freshwater systems, but in reality, the focus is entirely on marine fisheries with further bias towards commercial fisheries. This is alarming given that freshwater fishes represent some of the most imperilled taxa on the globe and that freshwater ecosystems face a large number of threats such as climate change, habitat alteration, fragmentation, water extraction, pollution and exploitation (Richter *et al.* 1997; Dudgeon *et al.* 2006). Moreover, the ecosystem services provided by inland fisheries (Holmlund & Hammer 1999) and their contribution to global food production, especially in developing countries, should make inland fisheries high priority for monitoring. There are a variety of reasons why status reports for inland fisheries are difficult to generate, but the challenges tend to relate most inland fisheries being evaluated and managed at a regional or state/provincial level and that there tends to be a lack of coordinated data collection, information management systems and analysis. In most developing countries, and even for many fisheries in developed countries, basic catch and harvest statistics are simply not collected. Further challenges with inland fisheries include most jurisdictions fish being used by multiple sectors (e.g. aboriginal, commercial, recreational) that involve a diversity of capture practices dispersed across broad landscapes (rather than focused on coastal zones and ports as in marine fisheries), which complicates the ability to obtain data needed to generate status reports.

Canada and the United States of America (US), herein referred to as North America, include some of the most high-profile and developed fisheries in the globe, although to date there have been few attempts to generate status reports the national scale (but see Pearse 1988 for a Canadian example) and none at the continental scale. Given that inland fisheries in North America are the focus of arguably some of the most intensive assessment and management, one might presume that developing a status report for North America would be comparatively easy relative to other continents. Certainly such a status report would be useful to identify the general trends in resource use and management, the threats faced by inland fisheries, and the needs and opportunities for improving sustainable management of North American fisheries. The inland fisheries of North America are diverse in terms of the sectors that harvest fish (all three sectors are active in North America), the waters fished (e.g. farm ponds, montane rivers, the Laurentian Great Lakes) and the species targeted (from Arctic coldwater fish to warmwater fish in Florida wetlands).

The objective of this paper is to summarise the status of inland fisheries in North America. The FAO (1992) definition for inland fisheries, which are those carried out in freshwater or estuaries and whose target species are those that spend all or part of their life cycle therein, is adopted. Initially, an overview of the biographical context of North America is provided to give an appreciation of the size of the continent and the rich freshwater resources. Next, each of the three fisheries sectors (i.e. aboriginal, commercial, recreational) is covered, first by providing a brief overview of their history and then of their current status. Threats that face inland fisheries are discussed as well as their management in North America, followed by a brief discussion on perspectives for the future of inland fisheries in North America.

It is recognised that some definitions of North America extend to include a variety of countries in the Caribbean (e.g. The Bahamas, Cuba, Jamaica) and Latin America (e.g. Mexico), some but not all of which have inland fisheries resources. However, for the purpose of this paper, the focus is exclusively on Canada and the US given that materials were generally available in English and the relative similarity in fisheries management institutions and approaches. In addition, little attention is devoted to the Laurentian Great Lakes given that their status is covered separately (Goddard *et al.* 2013). It is recognised that other terms can be used to describe various fisheries sectors (e.g. see UN FAO online glossary of fishery terms), for example, aboriginal fisheries in North America are typically categorised as subsistence fisheries, although that definition is often inappropriate given that pure subsistence fisheries does not allow for trade or sale of harvested products. In North America, aboriginal peoples fish for subsistence, ceremonial purposes and for small-scale commercial enterprise. There are also non-aboriginal fishers that participate in fishing for subsistence purposes, although that is often accomplished with recreational gear types. The term aboriginal has been adopted rather than subsistence to recognise the longstanding and continued important role that aboriginal peoples play in the use and management of fisheries as well as the many values that aboriginals place on fish

and fisheries. Given the limitations in presenting a continental-scale status report in a short article such an effort is far from exhaustive, but it is hoped that this exercise will stimulate more comprehensive status reports of inland fisheries in North America, as well as abroad.

Biogeographical context

To provide context for the inland fisheries resources in North America, it is useful to present some basic facts with respect to the geography of the two countries (i.e. US and Canada; Table 1). Collectively, North America has a population of approximately 0.45 billion, which is <10% of the global population. Population density within North America varies greatly, with the densest areas in urban centres in the US and the least populated areas in northern Canada. The Laurentian Great Lakes contain 20% of world's surface fresh water, and Canada alone has more than 2.4 million lakes (Table 1). Several of the world's largest river basins also occur in North America, including the Mississippi, St. Lawrence, Colorado, Yukon and Columbia. In general, fish species richness in North America is relatively low (Table 1), particularly in the north, relative to tropical and subtropical regions. However, a considerable proportion of freshwater fish species in North America are imperilled (Table 1; See Jelks *et al.* 2008). Unlike other areas of the world (e.g. South America, Asia) where there are many freshwater fish species yet likely to be discovered and described, the fish communities in North America are reasonably well studied and population trends of some species such as those of economic value (e.g. gamefish) or those that are believed to be imperilled tend to be subject of population monitoring. As such, the estimates of threatened species (see Table 1) are probably more reliable than other regions of the world. There have been several high-profile extinctions and extirpations, which can be partially attributed to overexploitation by a variety of sectors. For example, blue walleye, *Sander vitreus glaucus* (Hubbs), was fished to extinction in the Great Lakes in 1960, although populations were also negatively affected by threats external to fishing such as poor water quality and habitat alteration (Kennedy 1966). Both countries have coastal areas on the Atlantic, Pacific and Arctic Oceans and thus have a combination of marine and freshwater fisheries. Because fisheries operate in both realms (marine and freshwater) and because diadromous species move between both realms, there is complexity with respect to monitoring and reporting of fisheries statistics. In Canada, there is a regular (5-year interval) national-scale survey of the recreational fishery with a focus on fresh water. In Canada, most recreational fishing activity (93.7%) takes place in freshwater, whereas in the US the division between freshwater and marine effort is more equitable, although difficult to quantify with certainty given the way in which recreational fisheries statistics are collected in different realms by two separate agencies.

Table 1. Characteristics of the US and Canada relevant to inland fisheries and their status

	US	Canada
Population	310 500 000	34 250 000
Land area (km^2)	9 826 675	9 984 670
Water surface area (% of total land area)	6.7%	8.9%
Total renewable water (km^3)	3069	3300
Total marine coastline (km)	19 924	202 080
Number of lakes*	~1 700 000	~2 400 000
Number freshwater species	822	177
Number threatened freshwater species	123	13

*Estimated using data from Downing *et al.* (2006).

Historical and contemporary perspectives

Given the fundamental differences in the three fisheries sectors, and even the immense amount of intra-sectoral diversity (e.g. within the recreational fishing sector there are very different fisher typologies such as specialist anglers, those that release all fish and those that harvest all fish), each sector is first discussed on their own, covering both historical and contemporary perspectives.

Aboriginal fisheries

In North America, the historical importance of fish in the food economy of any tribe depended on the species of fish available in the area, the type of fishing equipment and skill possessed by the tribe, and the tribe's attitude towards fish as a food (Rostlund 1952). Certainly in British Columbia, fish have been a staple food, with anthropological evidence suggesting an exceptionally high consumption rate of 91 kg $fish^{-1}$ $person^{-1}$ yr^{-1} (Pearse 1988). For context, in 2007, the annual consumption rate for fish in Canada (for all groups) averaged 23.8 kg $person^{-1}$ yr^{-1} (FAO 2007). Similarly, tribes around the Great Lakes (e.g. Hurons, Iroquois, Ojibway) relied heavily on fish in their diet (Notzke 1994), with archaeological evidence indicating the existence of subsistence fishing on Lake Huron for at least 2700 years (Pearse 1988). By contrast, tribes living on the plains rarely utilised fish (Notzke 1994). This was due in part to limited access to the resource, and the belief by many members of the Blackfeet that fish were

unclean (Ewers 1958). For many tribes, fishing activities not only provided food for immediate nutritional needs, but also materials for trade (Ferguson & Duckworth 1997; Buklis 2002; Gobalet *et al.* 2004). Fish also represent a cultural and spiritual significance in many tribes and as such are used in family and place names, educational stories and ceremonies (Garibaldi & Turner 2004). The involvement of youth in fishing activities and ceremonies also presented a way to pass on traditional knowledge on fish natural history and fishing techniques to younger generations, and keep the aboriginal spirit alive (Barnhardt & Kawagley 2005).

A variety of fishing gears have been used by aboriginal groups over time to collect fish including gill nets, dip nets, seine nets, fish wheels, spears, weirs and rod and reel. The species caught are as diverse as the gear types used and are dependent on the geography of the tribe and the water bodies fished. Pacific Northwest aboriginal groups for instance focused on charr (*Salvelinus* spp.), salmon (*Onchorhynchus* spp.), smelt, *Osmerus mordax mordax* (Mitchill), trout (*Onchorhynchus* spp.), lake whitefish, *Coregonus clupeaformis* Mitchill, as well as burbot, *Lota lota* L., suckers (*Catostomus* spp.) and northern pike, *Esox lucius* L. (Buklis 2002), while lake sturgeon, *Acipenser fulvescens* Rafinesque and whitefish were particularly popular as food fish with aboriginal groups from the Great Lakes region (Whitaker 1892; Ferguson & Duckworth 1997). Many of the same species of fish are harvested today and in historical fishing grounds in instances where fish populations have not been impacted by development; however, numerous short duration trips are made as opposed to longer traditional expeditions (Berkes *et al.* 1995).

Information on the current harvest rate of aboriginal fisheries is difficult to obtain as these numbers are not consistently recorded across North America, and data are often held by tribes and not shared with state/provincial fisheries agencies emphasising the need for coordinated and integrated information management systems. Estimates by Pearse (1988) suggested that the aboriginal fisheries sector in Canada harvested approximately 9000 t yr^{-1} in the 1980s. Some of the most well-documented aboriginal harvests are in Alaska, where the Alaska Department of Fish and Game, Division of Subsistence conducts comprehensive surveys of even the most remote rural communities (see Magdanz *et al.* 2010). A total of 104 kg $fish^{-1}$ $person^{-1}$ yr^{-1} was reported for rural Alaska in 2001 (ADFG 2001). While some tribes in North America have increased harvests over the years, others are stable, and some harvests are declining. Declining trends reflect availabilities of other food sources (e.g. wild game and domesticated livestock), and particularly in the Arctic, a decreased use of fish as food for sled dogs (Pearse 1988; Fall 1990). Fluctuations in harvest rates can also depend on changes in aboriginal fishing rights and availability of fish and fishing areas owing to changes in population abundance and habitat alteration.

Understanding native fishing rights is complex, as even within Canada, there are regional variations (Notzke 1994). Treaty rights, aboriginal rights, natural resources transfer agreements, constitutional rights and comprehensive land claim settlements often give assurance to aboriginals that they are permitted to carry on traditional fishing, but increasingly they are subject to some level of governmental regulation (Pearse 1988). Similarly in the US, there is much federal regulation on aboriginal fishing rights (see Meyers 1991; Buklis 2002). The continued preservation of traditional subsistence fishing will best be guaranteed by providing North American aboriginals with an effective role in managing their affairs (Meyers 1991). Indeed, co-management has become more common since the 1990s (Notzke 1995), and there have been efforts to build capacity for stock assessment and management, such that some tribal groups (e.g. Columbia River Inter-Tribal Fish Commission; Anishinabek/Ontario Fisheries Resource Centre) have become leaders in the generation and provision of both 'western' science and traditional ecological knowledge to support fisheries management.

Commercial fisheries

Inland commercial fisheries in Canada commenced on the Great Lakes in the early 1800s (Pearse 1988), with the first production records collected as early as 1867 (Baldwin & Saalfeld 1962). Initially, the majority of the catch was exported to the US to support growing urban markets (Kennedy 1966). With increasing market opportunities and the construction of the railway, inland commercial fishing operations expanded to the west and the north (Adams 1978; Gislason *et al.* 1982). Commercial fisheries were established in Winnipeg, Manitoba in 1882 (Grant 1938), which saw exports to the US exceeding local sales within 2 years (Kennedy 1966). Development of a commercial fishery on Great Slave Lake in the Northwest Territories occurred in 1945, but there, like in other places in the northern prairie provinces (e.g. Lake Manitoba, Lake Winnipeg), fishing conditions were challenging owing to prolonged winters and profits were low due to high transportation costs (Kennedy 1966; Pearse 1988). In 1969, The Freshwater Fish Marketing Corporation (FFMC), a federal crown corporation, was established in an effort to stabilise and improve the economy through productive commercial fishing operations (Ashcroft *et al.* 2006). The FFMC was the single buyer for

small commercial fishers in north-western Ontario, Manitoba, Saskatchewan, Alberta and the Northwest Territories, while the larger fishing enterprises on the Great Lakes had access to a greater number of buyers and processors (Fisheries & Marine Service 1978). In 1974–1975, the commercial harvest in Canada was 43 765 t with a landed value of approximately $18 million dollars (CAD) (Falkner 1976). In 2006, the total landings were 32 029 t of fish, with an approximate landed value of $68 million (CAD) (DFO 2008). Canada's inland fisheries employs approximately 10 000 people directly (mostly in Ontario, Manitoba, and Saskatchewan) and provides additional jobs to industries supporting the transportation, processing, servicing and marketing aspects of commercial fishing, not to mention the nutritional benefits of providing fish protein (Pearse 1988).

In the US, inland commercial fisheries also began in the 1800s with developments on the Great Lakes (Bogue 2000), as well as other inland waters such as the Mississippi River (Carlander 1954) and Lake of the Woods (Carlander 1949). The volume of the fisheries resources in these areas led to increased settlement, particularly in the Great Lakes region (Whitaker 1892). Indeed, the 1890 census showed one-sixth of the entire American population occupied the six states surrounding the Great Lakes (Whitaker 1892). In 1954, the total catch of the freshwater fishery in the US was 64 071 737 kg, which came mainly from the Great Lakes, Lake of the Woods, Rainy Lake, Lake Namakan, and the Mississippi River (Anderson & Power 1956). At this time, it was believed that inland fisheries in the US as a whole were largely unexploited and that there was much potential for this industry to produce large quantities of fish for food and other purposes (Riggs 1958). Low exploitation of freshwater fisheries was due mainly because fish were not a favoured protein source in America compared with beef, pork and poultry, and also owing to conflict with sport fishing interests (Riggs 1958). For example, in Florida in 1946, the Game and Fresh Water Fish Commission promulgated rules which prohibited the sale of any freshwater game fish, and made it illegal to use most types of fishing gear popular to commercial fishing (e.g. haul seines, wire pots, pound nets, hoop nets, gill nets, trammel nets), presumably in recognition of the economic benefit of the recreational fishery (Dequine 1950). Multi-sectoral conflict continued to affect inland commercial fishing and saw eventual closing of the industry in the US waters of the lower Great Lakes in favour of recreational fishing (Pearse 1988). While determining the current landings and total economic value of inland commercial fishing is challenging owing to combined reporting of both freshwater and marine fish by the National Oceanic and Atmospheric Administration (NOAA; note – although NOAA does not manage inland waters they are responsible for generating national statistics for the UN FAO statistical reporting), the industry is still alive in the US and employs approximately 700 full-time fishers in the Great Lakes region alone (Brown *et al.* 1999).

In general, the main targeted species for North American inland commercial fisheries, particularly in northern regions, have included lake whitefish, northern pike, lake sturgeon, rainbow smelt, walleye, *Sander vitreus* (Mitchill), white sucker, *Catostomus commersonii* (Lacepède), yellow perch, *Perca flavescens* (Mitchill), arctic char, *Salvelinus alpinus alpinus* L., inconnu, *Stenodus leucichthys* (Güldenstädt), sauger, *Sander canadensis* (Griffith & Smith), Pacific salmon, *Oncorhynchus tshawytscha* (Walbaum), alewife, *Alosa pseudoharengus* (Wilson), and American eel, *Anguilla rostrata* (Lesueur) (Rodger 2006). In the Mississippi River, commercial catches are dominated by carp, *Cyprinus carpio* L., buffalo, *Ictiobus cyprinellus* (Valenciennes), catfishes (*Ictalurus* spp. *Pylodictis* spp.) and drum, *Aplodinotus grunniens* Rafinesque. While the popularity of some species increased as populations of other species declined [i.e. paddlefish, *Polyodon spathula* Walbaum, became a main source of caviar when sturgeon populations decreased (Carlson & Bonislawsky1981)], others have remained consistently favoured [e.g. yellow perch and walleye in the Lake Erie fishery (Koonce *et al.* 1999; Kinnunen 2003)]. The baitfish industry, which has become an important economic component of inland commercial fisheries [estimated at $29 million USD per year in 1985 in Ontario, and $145 million US$ per year in 1992 for six north-central states combined (Illinois, Michigan, Minnesota, Ohio, South Dakota, Wisconsin)] targets small-bodied species such as shiners, dace, minnows and darters that are sold to recreational anglers (Litvak & Mandrak 1993; Meronek *et al.* 1997).

Just as target species have changed over time, so have the use of a variety of gear types and vessels. As inland fisheries in North America take place on a wide variety of water bodies, ranging in size from a few square kilometres to more than 82 000 km^2 (i.e. Lake Superior), vessels range from small boats with outboard engines to 25-m ships that fish in the Great Lakes (Pitcher *et al.* 2002). The choice of gear also depended on location, and innovative technologies (Brown *et al.* 1999). Pound nets used to be the most popular gear on the Canadian side of Lake Erie, but decreased steadily as restrictions on gill net tugs were relaxed, and continued to decrease with legalisation on trap nets in 1950 (Kennedy 1966). Seine nets, fyke nets, set lines and otter trawls have also been used, and have all seen modifications based on changes in material fabrications (e.g. twine mesh, to cotton mesh, to monofilament mesh) and other technological innovations,

as well as shifts in fish distribution and behaviour associated with habitat changes (Kennedy 1966; Brown *et al.* 1999).

Recreational fisheries

Shortly after European settlers arrived in North America, recreational fishers began to exploit the rich waters present. Early recreational fisheries would have involved fishing from shore or use of non-motorised wooden boats or canoes in lakes, rivers and streams. In northern clines, ice fishing would have occurred during winter months. Natural lakes are common, particularly in Canada and the northern parts of the US, creating extensive inland fishing opportunities. Streams and rivers were also immensely popular for early recreational fishers, especially for those targeting salmonids or other diadromous fish. As mills were constructed and agriculture expanded, small impoundments and farm ponds became important inland recreational fisheries, particularly for warmwater fish such as largemouth bass, *Micropterus salmoides* (Lacepède), crappie, *Pomoxis nigromaculatus* (Lesueur), sunfish (*Lepomis* spp.) and brown bullhead, *Ameiurus nebulosus* (Lesueur). Beginning in the 1940s, both private and public (e.g. put-grow-take fisheries for rainbow trout, *Oncorhynchus mykiss* [Walbaum]) sport-fishing ponds grew in popularity as the science and management of ponds and small impoundments advanced (Meehean 1952). The number of ponds in the continental US grew from approx. 20 000 in the 1930s to over 2 million by 1965 (Swingle 1970). Current estimates exceed 2.6 million ponds and small impoundments (Willis *et al.* 2010). In 1991, 35% of 30.1 million inland anglers in the US fished in ponds smaller than 4.2 ha (USDI 1993). It is believed that the majority of pond fisheries harvest more fish than are released, with protein being used for private consumption (Willis *et al.* 2010). With growing demand for hydroelectricity and need for flood control, the 1900s saw the creation of many large reservoirs that provided important recreational fishery opportunities. In 1970, reservoirs accounted for ~40% of all inland fisheries opportunities in the US (Jenkins 1970). Reservoir science has also advanced rapidly, although these fisheries tend to be supported with stocking programmes (Miranda & Bettoli 2010), presumably due to habitat limitations and degradation (Miranda *et al.* 2010). Although various angling clubs have held competitions for decades, in the 1970s competitive angling events became commonplace, particularly for black bass and walleye. Event format has changed through time with most now being primarily live release. In North America there are over 120 000 such events in freshwaters on an annual basis (Schramm *et al.* 1991), and these are somewhat unique to this continent, especially given the level of celebrity and financial benefit for the winners.

Catch-and-release was rare among early recreational anglers in North America with many archival photographs of large stringers of trophy fish signifying that fish were both large and plentiful and society in general was not conservation oriented. During that period there was little monitoring of fish harvest or effort in the recreational sector so it is difficult to provide commentary on long-term trends or historical fisheries. More recently, the development of a strong conservation ethic and move towards selective harvest has resulted in the voluntary release of a significant proportion of the recreational catch (Arlinghaus *et al.* 2007). Although catch-and-release dates back to Europe prior to discovery of North America, it is perhaps most vigorously embraced in North America and somewhat unique relative to other areas where release rates tend to be lower (reviewed in Arlinghaus *et al.* 2007). Use of harvest regulations that mandate release of some fish has further elevated release rates in North America. In Canadian inland waters in 2005, there was a total estimated recreational catch of 215 million fish and harvest of 75 million fish (i.e. release rate of ~ 66%; DFO 2006). Similar data do not exist at a national scale for US inland waters. Despite high release rates, there is some evidence that inland recreational fish populations in North America are in decline, which is partly associated with threats that are external to the sector. Nonetheless, a seminal paper by Post *et al.* (2002) revealed that a number of high-profile recreational fisheries in Canada were showing evidence of collapse including rainbow trout, walleye and northern pike, which appeared to be associated with internal threats. The declines were attributed to the complexity of angler behaviour, lack of long-term monitoring and failure to consider recreational fishing as a potential threat.

Recreational fisheries are also important aspects of the culture of some regions, particularly in rural areas where freshwater abounds (e.g. Minnesota, northern Ontario), and are the focus of various festivals, mascots for sports teams and larger-than life replicas. A wide spectrum of the population participates in recreational fishing including women and children, although participation rates have been in decline in recent years (~2% per year for adults between 1995 and 2005 in Canada; DFO 2006). In Canada, 3.2 million adults fished at least once in inland waters in 2005 (DFO 2006) and in the US, inland recreational anglers numbered over 25 million in 2006 (ASA 2008). The social benefits of recreational fishing are well known in North America, especially as it relates to leisure, relaxation, and connection to friends, family and the natural world (Arlinghaus & Cooke 2008). In

urban areas there have been great efforts to engage youth (e.g. hooked on fishing, not drugs programme). Economically, recreational fisheries are very important because of the many ancillary economic spinoffs related to, for example, travel, fuel, vehicles, boat sales, fishing gear, tackle and guides. In Canada it is estimated that $7.5 billion was contributed to the economy in 2005 as a result of the direct and indirect expenditures on recreational fishing (DFO 2006). In the US, over 767 000 jobs are associated with the inland recreational fishery with a total economic value of $95 billion (ASA 2008). In both Canada and the US, anglers directly support fisheries management, access and education via licence sales (in both nations) and excise taxes (in the US, for example, the Dingle-Johnson, Wallop-Breaux Federal Aid in Sport Fish Restoration Act in the US collects excise taxes on fishing equipment, fish finders, motorboat fuels, small engine fuels and import duties).

Status and threats to inland fisheries in North America

For two countries where inland fisheries have significant economic and social benefits (partially summarised above), and where there are many well-established fisheries management agencies, there are few quantitative standard metrics regarding effort, catch, harvest and total economic benefit at national or continental scales. While an attempt was made to generate a status report for the inland fisheries in North America, it was difficult to do so in a truly quantitative manner. Nonetheless, using available data and a number of assumptions and extrapolations, the total inland harvest for inland waters in North America is estimated at 487 989 t, which is based on an estimate of 419 100 t harvested by the recreational sector (actual capture is much higher), 64 058 t by the commercial sector and 4831 t by the aboriginal sector. Some of the limitations with this estimate include the assumption that the recreational harvest rates in Canadian waters in 2005 were representative of US waters, that the average mass of a harvested recreational fish was 0.635 kg [same value used by Cooke and Cowx (2004) but comes from marine recreational fish], that Canadian inland commercial fisheries in 2006 were identical to current harvest by both countries today, and that the aboriginal fisheries represent a 1% incremental increase in harvest over the combined recreational and commercial harvest. This value is higher than those reported in FAO fisheries statistic year books for Canada and the US, likely because they fail to include the recreational sector in their calculations. In Canada there is decent information on inland recreational fisheries, but little national-level information on aboriginal or commercial fisheries. In the US, the marine fishing statistics are quite comprehensive but inland data are not easily available on a national scale. Some of these challenges are symptomatic of most inland fisheries being managed by provincial or state agencies (Nielsen 1993), but other challenges include the dispersed effort of recreational fisheries, lack of adequate personnel in resource management agencies, lack of systematic and standardised sampling and lack of information management systems. Although such governance makes sense, there should also be a mechanism where data from provincial and state agencies are summarised on a national scale. There is a need for greater reporting and more transparency in collection of what are simple but critical fisheries statistics to enable the generation of landscape-scale status reports.

Another important element of evaluating status is commentary on the quality of the fisheries. Quality in the context of ecosystem management does not simply mean lots of big fish. What is needed is better long-term data on trends in fish populations (abundance and age/size structure, sex ratios, community structure). Other relevant information would include level of bycatch in non-selective aboriginal and commercial fisheries and information on recreationally captured fish that are released. Demographic information is available for the recreational sector, at least for those that purchase licences, but less information is known about non-licensed anglers such as youth and seniors.

As a whole, it is difficult to argue that the inland fisheries, especially for the recreational sector, are not vibrant and healthy given the significant socio-economic benefits that they provide. However, there are certainly areas within North America where that is not the case owing to severe habitat alteration (e.g. barriers to migration, urbanisation, agriculture; Jelks *et al.* 2008), lack of water (drought, irrigation, water taking; Lake 2003), invasive species (Kolar & Lodge 2002) and overfishing from various sectors (Allan *et al.* 2005; Humphries & Winemiller 2009). In some areas, the contaminant levels of inland fish are so great that human consumption is restricted via consumption advisories (Reinert *et al.* 1991). The incremental effect of all of these stressors, on top of fishing mortality (both release mortality and harvest – historical and current) certainly is worrisome, particularly as the human population continues to grow, competition for water increases, and climate change (see Table 2). In some areas, already there is insufficient water and fisheries productivity to support all sectors. In other areas, some water bodies are in good condition whereas the fisheries in others have exhibited declines and require stocking to restore fish populations. Therefore, painting a continent as big and diverse as North

America with a single brush is not entirely informative, but it is a first step. Although historical data are lacking in most cases, there is a general belief that the fishing quality in North America has declined – both in the quantity and size of fish, although there has also most certainly been a shifting baseline in the inland waters (Humphries & Winemiller 2009).

Given that the dominant user of inland fisheries in North America is the recreational sector, for which harvest is relatively low owing to catch-and-release, fisheries in North America face somewhat different threats than those in other regions of the world (Welcomme *et al.* 2010). The high release rates of fish by recreational fishers may not occur elsewhere and the angling fraternity in North America has significant political clout. Moreover, in both Canada and the US, fisheries represent public trust resources with significant socio-economic value so there is much interest in ensuring that they are managed sustainably. In Canada, where all three fisheries sectors overlap (e.g. the Lower Fraser River of British Columbia), aboriginal peoples have priority access to fish for ceremonial purposes and food as a result of the Sparrow Decision (Pitcher *et al.* 2002). Moreover, government fisheries regulations in Canada cannot unduly restrict an aboriginal right to fish. Such rights have led to inter-sectoral conflict. Indeed, wherever different sectors co-occur, there is a tendency for conflict to emerge over access to fish and fishing opportunities as well as discourse related to the relative negative impacts of the different sectors. Additional conflict exists between recreational fishers and animal rights groups that take objection to fishing for fun. Given that some of the greatest threats to all sectors are external (e.g. habitat alteration, environmental change, invasive species, lack of public appreciation for inland fisheries), there may be more benefit to addressing common problems with a unified front (Cooke & Cowx 2006).

Table 2. Summary of internal (i.e. threats that are a result of the fisheries themselves) and external (i.e. threats that come from other resource users or environmental factors) threats facing the aboriginal, commercial and recreational inland fisheries in North America

Threats	
External	Internal
Aboriginal	
Inter-sectoral conflict	Bycatch and discard mortality
Racism	Loss of traditional culture
Lengthy treaty negotiations	Loss of traditional ecological knowledge
Environmental change and habitat alteration	Lack of capacity for co-management
Invasive species	Lack of knowledge and predictability?
Water quality and quantity	
Commercial	
Inter-sectoral conflict	Bycatch and discard mortality
Operational costs (fuel, boat, insurance, etc.)	Ageing fishers with little replacement
Environmental change and habitat alteration	Evolutionary impacts of fishing [i.e. selective harvest and fisheries induced evolution (FIE)]
Invasive species	
Water quality and quantity	
Recreational	
Anti-fishing movement	Intra-sectoral conflict
Inter-sectoral conflict	Release mortality
Reductions in access to fishing opportunities	Declining participation rates
Complexity of regulations	Ageing angling community
Environmental change and habitat alteration	Evolutionary impacts of fishing (i.e. FIE)
Invasive species	
Water quality and quantity	

Management of inland fisheries in North America

Unlike some jurisdictions, particularly in Europe, where inland fisheries rights are largely private, in North America fish (as well as wildlife) are generally considered public resources in accordance with the Public Trust Doctrine (PTD), which is a part of common law and has roots in Roman civil law (TWS 2010). The PTD has three core principles relevant to inland fisheries management in North America: (1) fish and fisheries are public resources; (2) fisheries resources are managed by the government for the common good; and (3) scientific and resource management professionals hold fisheries in custodianship and serve as trustees who are accountable to the public. In recent years, rights-based fisheries management approaches have been used in North America (mostly in marine waters in the form of limited entry permits, individual fishing quotas, and local community-based or co-operative harvesting; see Hilborn *et al.* 2005). There are some historic rights-based inland recreational fisheries in Canada called Crown leases and Crown reserves, as well as some limited private water access rights that are intended to limit access of anglers (e.g. for Atlantic salmon rivers in New Brunswick), however, they are not widespread. Rights-based fisheries also have been used for inland commercial fisheries in Canada, largely in the form of individual transferrable quotas (on Lake Erie and Lake Winnipeg) and at a community level in the Arctic (reviewed in Crowley & Palsson 1992). In North America, recreational fisheries are operated as a user-pay approach where licence fees support fisheries management by government agencies. This model is rather uncommon globally but has recently been adopted by some states in Australia.

In the United States, state governments are typically responsible for inland fisheries management. In Canada, activities are governed by the Canadian constitution, duly signed treaties and federal (especially the Fisheries Act) and provincial legislation, and provincial fisheries agencies tend to deal with inland fisheries management and monitoring. The PTD is the foundation for the North American model of resource management and is generally used in both nations. In a fisheries context, the North American model of management is information-based, meaning that research activities, stock assessments and knowledge are fundamental components of decision-making processes. However, there are several caveats to this approach. First, there is an assumption that adequate science and knowledge exists or can be obtained. The second caveat is that credible science-based information is indeed the basis for decision-making. Rarely are both of these caveats satisfied owing to finite resources and the socio-economic and political human dimensions that play an important role in fisheries management. In reality, there is always some level of uncertainty with respect to fisheries even in a continent that is relatively rich with expertise, technological capacity and financial resources. However, basic stock assessment is time consuming and expensive and thus cannot be done on every system in every year. For example, Minnesota has 11 842 lakes and more than 6500 natural rivers and streams totalling some 111 000 km. Monitoring all of these waters is simply not possible given today's resources and technologies. Some jurisdictions such as Ontario have adopted a landscape approach to fisheries management where areas with similar geology, climate and zoogeography are managed in a uniform manner with monitoring restricted to a reasonable number of representative waters (Lester *et al.* 2003). Hence, commenting on the status of inland fisheries in North America is inherently challenging given that data are only available for a fraction of waters present.

Aboriginal fisheries are also inherently difficult to monitor given the sometimes acrimonious relationships that exist with natural resource agencies. However, co-management frameworks, when implemented, provide opportunities to generate high quality data on the status of fisheries. For example, such relationships are well developed in the US Pacific Northwest where several tribal governments play a fundamental role in the management of Columbia basin fisheries (Ebbin 2002). Inland commercial fisheries in the Great Lakes are highly regulated and monitored, largely owing to the bi-national management framework that has been established (Brown *et al.* 1999). However, in other areas of North America, even data on basic catch statistics are difficult to obtain. Additionally, few inland commercial or aboriginal fisheries are required to record bycatch (of fish or other animals) despite inland byctch being a conservation problem (Raby *et al.* 2011).

Management of recreational fisheries in North America involves a number of tools including harvest regulations (Johnson & Martinez 1995) that focus on size (minimum, maximum or slot limit), bag limits (e.g. number of fish per day of species y), area closures (e.g. sanctuaries; Suski & Cooke 2007) and seasonal closures. Harvest regulations have been highly successful in protecting spawning biomass and allowing fish to mature and reproduce prior to harvest. Typically, seasonal closures are used to protect fish during the reproductive period. Although most jurisdictions in North America require licences (but not for youth or seniors), there are rarely effort controls *per se* aside from limits on the number of rods that an angler can use. In some cases harvest regulations are employed to try and actively alter the population or community structure but with such a strong emphasis on catch-and-release in many fisheries, sometimes the regulations do not achieve their intended result.

Beyond managing people, other common inland management approaches focus on the habitat or the fish. For example, addition of habitat structures in rivers and streams (Roni *et al.* 2002) or placement of gravel or timber in reservoirs (Summerfelt 1993) are common approaches for attempting to increase fisheries productivity. Habitat can also be altered via fertilisation, something that has been highly successful in some lakes in the Pacific northwest (Hyatt *et al.* 2004). Dam removal (Bednarek 2001) or installation of fish passage facilities (Roscoe & Hinch 2010) represents other types of habitat management that have the potential to improve or restore fisheries. Fish populations can also be managed directly through supplementation programmes. Stocking of fish for put-grow-take fisheries where there is no expectation of natural reproduction or stocking of fish to supplement wild populations or re-establish extirpated populations are common. Fish (both forage and sportfish) are also introduced to non-native waters to create new fishing opportunities or improve existing ones, but there are risks with such actions such as introduction of disease and competition with native species (reviewed Cambray 2003). In some cases, although the ecological consequences of introductions have had negative impacts on ecosystems, the fisheries opportunities they create can lead to some benefit (e.g. common carp specialised recreational fishery pacific salmon in great lakes). Through time there has been a reduction on the reliance on hatcheries for production of sportsfish owing to increased cost but largely owing to improvements in other aspects of fisheries management (i.e. managing harvest, habitat and invasive species) that allow for productive wild fisheries (e.g. wild trout management).

Given that there are relatively few places in inland waters where commercial or aboriginal fisheries operate without the recreational sector, management of multi-sector fisheries tends to occur so aboriginal and commercial sectors are not discussed on their own. Like recreational fisheries, inland commercial fisheries in North America are typically managed using size-based harvest regulations in addition to the more comment effort controls used in marine commercial fisheries. For example, in the upper Mississippi River two catfish species that were harvested commercially declined markedly from 1955 to 1984 owing to illegal overharvest of fish over the legal length of 33 cm (Pitlo 1997). In 1985 the minimum size was increased to 38 cm for commercially harvested catfish and following implementation of the new regulation, harvest rates and the value of the catch increased. Emphasising the inter-relationship of the fisheries sectors, the popularity (as a rank of preference) of channel catfish, *Ictalurus punctatus* (Rafinesque), in the creel of sport anglers increased from sixth in 1963 to second in 1994 (Pitlo 1997). Another example of a fishery used by multiple sectors is the paddlefish fishery in Kentucky and Tennessee. Timmons and Hughbanks (2000) estimated commercial and sport fishing exploitation and noted that in one lake most of the exploitation was commercial (i.e. Kentucky Lake, 88%) and in the other it was dominated by the recreational sector (i.e. Lake Barkley, 65%) emphasising that the relative effort of different sectors can vary over small spatial scales. There was additional complexity in the management of the fishery given that there were area closures for the commercial fishery but tagging studies revealed that fish moved into areas where they were legally harvestable such that the regulation was ineffective. In some cases, commercial harvest may not directly conflict with recreational fishers because of different targets but the consequences of commercially harvesting those fish can have community level changes that could influence the recreational fishery in a positive or negative manner (e.g. Schramm *et al.* 1985).

Prognosis and conclusion

Collectively, the three inland fisheries sectors provide substantial socio-economic benefit and regionally can have significant cultural value and yield a significant amount of food protein. Nonetheless, there are a number of internal threats that face these fisheries including over-exploitation and release mortality as well as external threats such as inter-sectoral conflict, regional and global environmental change, invasive species and habitat alteration (See Table 2). If inland fisheries in North America are to be sustainable in the future, there is a need to adopt management strategies that are holistic, coordinated and trans-jurisdictional given that most inland fisheries are managed at the more local, state/provincial and tribal level. There is need for information management systems and adoption of standard sampling methods (Bonar *et al.* 2009) to enable knowledge transfer among agencies and the development of status reports at the national and continental scale. It is also critical that management of fisheries not be isolated to a single sector. Furthermore, fisheries management tends to be most successful when focused simultaneously on the fish, their habitat and the people using the resources (Nielsen 1993). All stakeholders must recognise that although inland fisheries tend to not receive the same attention as marine fisheries, that the potential for local- and broad-scale irreversible changes in inland fisheries also exist and must be identified and addressed.

Inland fisheries will certainly undergo significant change in coming years, particularly in northern clines owing to climate change. Conflict with other non-fisheries users (e.g. recreational boating) for access to water and reductions in water quality will likely become greater problems as human populations increase. In addition, the need to protect endangered populations (fish and other taxa) may also limit fishing access or effort. New fisheries may emerge in the form of invasive species such as Asian carp in the Mississippi River. As the population ages, there is evidence that recruitment of new anglers is declining, which appears to be associated with a general trend of urbanisation and people becoming disconnected with nature. On the other hand, food security and the move towards eating locally may create new markets for freshwater fish provided that they have low contaminant loads and are considered healthy and taste good. There is also no doubt that the three sectors will continue to compete for access to fish. However, the best way forward is for the various fisheries sectors to focus on reducing inter-sectoral conflict so that efforts can be devoted to addressing the many common external threats such as habitat alteration, environmental change, fragmentation, pollution and introduction of non-native species.

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