FISH and FISHERIES

FISH and FISHERIES, 2016, **17**, 249–265

## Ghoti

### Ghoti papers

Ghoti aims to serve as a forum for stimulating and pertinent ideas. Ghoti publishes succinct commentary and opinion that addresses important areas in fish and fisheries science. Ghoti contributions will be innovative and have a perspective that may lead to fresh and productive insight of concepts, issues and research agendas. All Ghoti contributions will be selected by the editors and peer reviewed.

### Etymology of Ghoti

George Bernard Shaw (1856–1950), polymath, playwright, Nobel prize winner and the most prolific letter writer in history, was an advocate of English spelling reform. He was reportedly fond of pointing out its absurdities by proving that 'fish' could be spelt 'ghoti'. That is: 'gh' as in 'rough', 'o' as in 'women' and 'ti' as in palatial.

# Angling for endangered fish: conservation problem or conservation action?

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### Abstract

Recreational angling has been implicated in population declines of some marine and freshwater fish, but this activity is rarely considered as a threat or even halted when endangered species are targeted. Indeed, in some cases, anglers are drawn to fish for rare or endangered species. Conservation-oriented behaviours such as catch-and-release are often practiced voluntarily due to the ethics of anglers, yet even in these cases, some fishing mortality occurs. Nonetheless, there are many indirect conservation benefits associated with recreational angling. Here, we present a series of case-studies and consider whether catch-and-release angling for

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 DOI: 10.1111/faf.12076 

endangered fish is a conservation problem or a conservation action. If recreational angling activities contribute to population-level consequences that are contrary to recovery strategies, then angling for endangered species would seem to be a poor option. However, as revealed by several case-studies, there is much evidence that anglers are vocal and effective proponents of fish and habitat conservation, and for endangered species, they are often the only voice when other stakeholders are not engaged. Anglers may contribute directly to conservation actions via user fees (e.g. licences), philanthropic donations or by volunteering in research, education and restoration activities. However, it is important to quantify post-release mortality as well as understand the full suite of factors influencing a given population or species to know the potential risks. A risk assessment approach outlined in the paper may be used by managers to determine when the benefits of angling for endangered species outweigh the risks.

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*Received 14 Aug 2013*
*Accepted 11 Dec 2013*

**Keywords** Conservation, endangered fish, recreational angling, risk assessment

## Introduction

Globally, aquatic ecosystems and their associated ichthyofauna are among the most threatened systems and organisms on the planet (Warren and Burr 1994; Ricciardi and Rasmussen 1999; Powles *et al.* 2000). Freshwater ecosystems are threatened by habitat alteration, fragmentation, invasive species, water extraction, pollution, climate change and, to a lesser extent, exploitation (Richter *et al.* 1997; Allan *et al.* 2005; Vörösmarty *et al.* 2010). Marine ecosystems also face many threats including coastal development, environmental change (e.g. ocean acidification) and pollution (e.g. Gray 1997; Valiela *et al.* 2001; Halpern *et al.* 2007). However, the dominant factor influencing most marine fish populations has been commercial overexploitation, which has led to catastrophic collapses of a variety of predatory fish species (see Botsford *et al.* 1997; Jackson *et al.* 2001; Worm *et al.* 2006). Of course, the underlying driver for nearly all of the threats facing aquatic ecosystems and persistence of fish populations is human activity. Although the commercial fishing sector has traditionally been implicated in fish declines and extinctions, there is growing evidence that the recreational fishing (both post-release mortality and harvest) can have significant impacts (McPhee *et al.* 2002; Post *et al.* 2002; Coleman *et al.* 2004; Cooke and Cowx 2004, 2006; Lewin *et al.* 2006; Cowx *et al.* 2010). Interestingly, recreational fishing is rarely listed as a major threat in regional, national or international risk assessments (but see Cambray 2002). For example, the International Union for the Conservation of Nature (IUCN) Red listings rarely even cite recreational fishing as a limiting threat, partly because the IUCN listing rarely discriminates between types of fisheries (but see taimen, *Hucho taimen*, Salmonidae, as an example where legal and illegal recreational fishing are explicitly mentioned; Hogan and Jensen 2012). Given the thoroughness of most threat assessment processes, and despite the issues noted above, it is probable that in most instances, recreational fishing is only a minor threatening process, otherwise it would have been included in the suite of possible threat codes (Salafsky *et al.* 2008). Nonetheless, population declines attributed to recreational fisheries have certainly been documented, even though they initially went unnoticed (e.g. Post *et al.* 2002; Coleman *et al.* 2004), but such examples are still relatively rare. Moreover, Donaldson *et al.* (2011) reported that in general, gamefish were on average more threatened than non-game fish but that these same species tended to also be targeted by commercial fisheries. It is clear that there is a need to consider the role of recreational fisheries in aquatic conservation issues and to determine the extent to which angling effort focused on imperilled species is problematic.

Unlike commercial fishing, recreational fishing generally does not constitute an individual's primary source of obtaining food and is typically not sold or otherwise traded on export, domestic or black markets (Arlinghaus and Cooke 2009). A variety of gears can be used including rod and reel, traps, spears and nets, although for the purpose of this paper, we focused on rod and reel (i.e.

recreational angling) as it is by far the most common form of recreational fishing. The motivations for fishing are many and diverse, although there is certainly a strong leisure component for most anglers (Fedler and Ditton 1994). Recreational angling as an industry is worth hundreds of billions of dollars in developed countries (U.S. DOC 2002; Henry and Lyle 2003; DFO 2012), and in some developing countries, recreational fisheries can have a greater economic impact than commercial fisheries (Stage and Kirchner 2005). In terms of biomass, recreationally harvested fish (herein referred to as 'game fish') have been estimated to represent up to 12% of global fish catches (Cooke and Cowx 2004), and in some mixed-sector fisheries, it can represent up to 90% of the annual harvest (Coleman *et al.* 2004). On a global basis, participation rates for recreational fishing are quite variable (e.g. can exceed 45% of population in some Scandinavian countries), with the global average being ~11% (Arlinghaus and Cooke 2009). Some anglers in developed countries will spend thousands of dollars to travel to remote areas including developing countries to access unique fishing experiences (Ditton *et al.* 2002; Zwirn *et al.* 2005; Borch *et al.* 2008). For some, 'unique' simply implies experiencing a new environment and culture, but for others, there is explicit interest in attempting to capture a rare, strange or imperilled species (Ditton *et al.* 2002). What defines a game fish is ever-evolving (Donaldson *et al.* 2011) with growing appreciation for non-traditional species (often referred to as coarse species) such as catostomids (Cooke *et al.* 2005).

When fish populations (or in some cases species) are imperilled, commercial fishing is often curtailed or halted (even if not primarily responsible for the decline), particularly in developed countries or for multijurisdictional fisheries subject to management by regional fisheries bodies and organizations. Even when commercial fisheries are not halted or when compliance is poor, in some cases (see Vincent *et al.* in press), the international trade of endangered fisheries products is restricted using legal instruments such as the Convention on International Trade in Endangered Species (CITES). Even social marketing efforts such as the sustainable seafood movement can result in changes to commercial fishing practices such that it becomes socially unacceptable to harvest fish of a given species or population (Jacquet and Pauly 2007). However, to our knowledge, there are few examples where recreational fishing activities have been forbidden, even when populations or species are imperilled. In developed countries, management interventions that restrict or prohibit recreational harvest of threatened species commonly include limiting gear types or applying seasonal or area closures (e.g. Johnson and Martinez 1995), but rarely is recreational angling halted completely. In the case of catch-and-release, angling for threatened species is usually allowed, including in no-take protected areas, as fishing mortality is assumed (often without scientific study) to be low or negligible (Cooke *et al.* 2006).

Given the above, here we consider whether angling for endangered fish is a conservation problem or a conservation action. In the spirit of full disclosure, and recognizing that some of the issues associated with this topic are ethical and will be driven largely by personal values (Bryan 1977; Manfredo *et al.* 2003), it is important to note that several authors are avid recreational anglers and conduct research on recreational fisheries science. Previous authors have argued that recreational angling is an unethical activity (e.g. Balon 2000), particularly when fishing is purely for fun and fish are captured and released (see discussion in Arlinghaus *et al.* 2012 for context). However, we write this paper from the perspective that angling is a socially and morally acceptable activity (Arlinghaus *et al.* 2012) and instead focus on the conservation-oriented issue related to whether the potential risks associated with angling for endangered fish are outweighed by the benefits. Moreover, we assume (knowingly aware that there are exceptions) that if fish populations or species are endangered (nationally or internationally), then fisheries harvest would likely be prohibited. Therefore, we focus our discussion on the assumption that if recreational fisheries were to occur for imperilled fish, they would be released. Thus, hereafter all discussions of recreational fishing activities relate strictly to catch-and-release. We adopt a case-study approach (see Fig. 1 for species covered in case-studies) where we summarize the conservation problems and conservation benefits that have arisen due to recreational angling for a number of endangered marine and freshwater fish from around the globe. We also propose a framework for determining how valuable assessing the risks of recreational angling may be on a species-specific basis and provide a framework for determining whether catch-and-release recreational angling should be embraced vs. curtailed. We also discuss

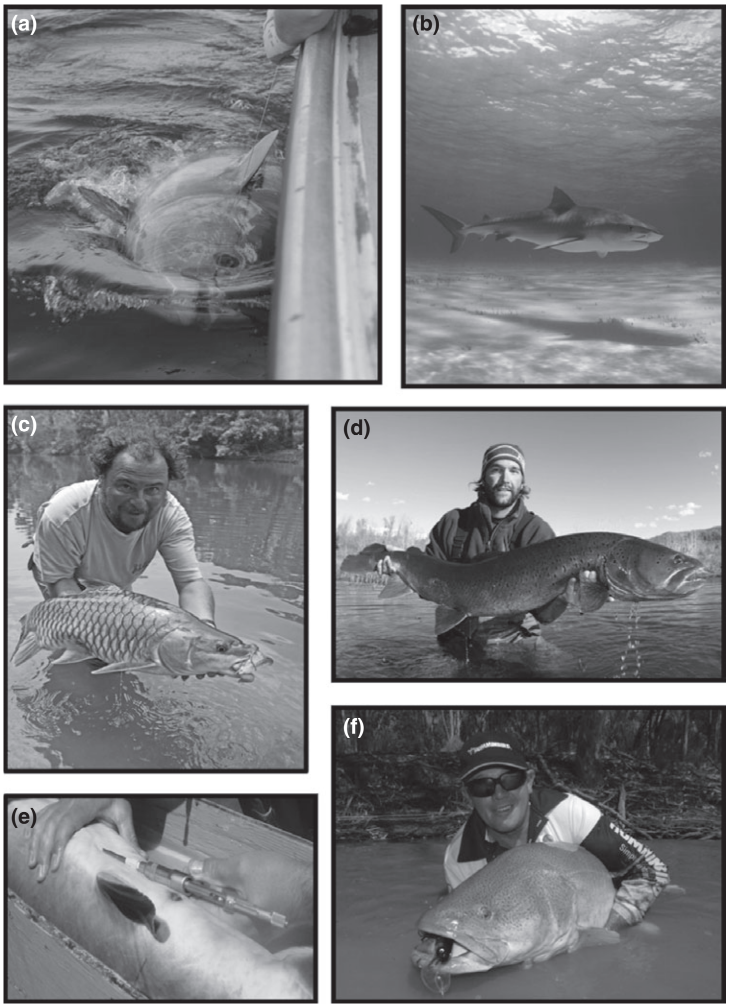

**Figure 1** Photo montage of species included in case-studies. (a) bluefin tuna being tagged as part of a collaborative project with charter boat captains in the Gulf of St. Lawrence (photo credit: Aaron Spaeres); (b) hammerhead shark swimming freely after being released by from a fisheries encounter (photo credit: Austin Gallagher); (c) mahseer released by angling tourist in India (photo credit: Steve Lockett); (d) taimen captured as part of a collaborative research project between anglers and researchers in Mongolia (photo credit: Zeb Hogan); (e) sturgeon injected with passive integrated transponder tag by fishing guides participating in collaborative research project (photo credit: Jason Thiem); (f) Murray cod capture by recreational angler (photo credit: Paul Butcher).

alternative management approaches that could be used to ensure that recreational angling is compatible with endangered species recovery.

## Case-studies

### Mahseers (*Tor* spp, Cyprinidae)

*Background, status and threats of endangerment*

Mahseers of the genus *Tor* are large cyprinids endemic to continental Asia with a natural distribution encompassing the trans-Himalayan region in the northwest to Sumatra and Borneo islands in the southeast (Nguyen *et al.* 2008). They are considered to be a cultural icon of diverse economic, recreational and conservation value throughout their range (Siraj *et al.* 2007). As one of the fiercest game fishes of the Indian subcontinent, known as the 'King of Indian aquatic systems' (Langer *et al.* 2001; Dhillon 2004), Mahseers are the prime focus of India's recreational fishing industry. Seven species of *Tor* are known to occur in India of which four are listed as 'Endangered' and one as 'Near Threatened' in the IUCN Red List of Threatened Species. Overexploitation and habitat loss has resulted in severe population declines of the four 'Endangered' species (*T. khudree*, *T. kulkarni*, *T. malabaricus*, and *T. putitora*). The Deccan mahseer, *T. khudree*, in particular have been subjected to very high levels of exploitation and its fisheries in several rivers and reservoirs are under a threat of imminent collapse (Raghavan *et al.* 2011). Anecdotal information as well as observations of recreational fishers also reveals that golden mahseer, *T. putitora*, of sizes of interest to recreational anglers are now absent from the majority of popular fishing sites (reviewed in Everard and Kataria 2011).

*The role of anglers in conservation*

The recreational fisheries sector has played a significant role in conserving mahseer stocks and habitats in India (see Pinder and Raghavan 2013). These conservation efforts have focused on protecting prime mahseer habitats, procuring river stretches that harbour mahseer through long-term leases from the government, advocating catch-and-release and stocking of captive bred fingerlings (Nautiyal 2006; Dinesh *et al.* 2010). The income generated from recreational fisheries, especially in the Cauvery river, has also helped to effectively control illegal (often destructive) fishing of mahseer through the establishment of antipoaching camps, as well as rehabilitation of former poachers as fishing guides (*Ghillies*), thus providing alternative employment and related societal benefits (Pinder and Raghavan 2013). In the Himalayan rivers, the recreational fishing sector has created an incentive to conserve the mahseers, often involving local communities through responsible ecotourism ventures (see Everard and Kataria 2011). Although no formal scientific studies have yet been conducted, anecdotal evidence, as well as unpublished data from angler log books, suggests a dramatic increase in the total number of fish caught over time in the river Cauvery, indicating elevated levels of recruitment (see Pinder and Raghavan 2013). Overall, mahseers in India receive more protection in leased (managed by property owners) riverine habitats and recreational angling centres when compared to those stretches where angling is not officially permitted (Nair 2010).

**Taimen (*Hucho taimen*, Salmonidae)**

*Background, status and threats of endangerment*

Taimen occur in swift flowing rivers and streams of the Caspian and Arctic drainages in Eurasia and portions of the Pacific drainage in Mongolia, Russia and China (Holcik *et al.* 1988). Taimen are large (maximum size ~2 m TL) long lived (>50 years) and relatively late to mature, making them vulnerable to over-exploitation. Generation time is estimated at about 17 years for an unfished population (Olaf Jensen, Rutgers University, personal communication). Previously abundant in large areas of Russia, Mongolia and China, taimen populations have declined significantly in most parts of their range (Kucherenko 1988; Ocock *et al.* 2006). In Mongolia, fish have disappeared from rivers near town centres and downstream of mining areas (Ocock *et al.* 2006). In China, populations have declined due to pollution and over-harvest (Guangxiang *et al.* 2006). As a result of these declines, taimen are listed as vulnerable by IUCN and endangered by Mongolia and China. The main threats to taimen appear to be subsistence and small-scale commercial fishing, construction of dams and reservoirs for hydropower, and pollution from mining, but recreational fishing also poses a real threat to taimen populations when anglers harvest large numbers of adult fish for food or trophies (Ocock *et al.* 2006). Taimen are an increasingly popular target of recreational anglers and seemingly moderate harvest can lead to significant declines, especially in the abundance of mature fish (Misha Skopets, independent consultant, personal communication). Jensen *et al.* (2009) modelled the effects of recreational catch-and-release, recreational catch-and-kill and subsistence harvest on a population of taimen in the Eg-Uur watershed of Northern Mongolia and found that both subsistence and catch-and-kill recreational angling resulted in high probability of population extirpation (Jensen *et al.* 2009). In contrast, the effects of best practice (single, barbless hook, minimal handling, etc.) catch-and-release recreational angling on abundance, biomass and survival were minimal (Jensen *et al.* 2009).

*The role of anglers in conservation*

Mongolian taimen are the focus of several new sportfishing-oriented conservation projects. In the Eg-Uur River Basin in Northern Mongolia, an organization, the Taimen Conservation Fund, was established to direct revenue from recreational angling to fund enforcement and research activities. The Taimen Conservation Fund proposed several new regulations for recreational taimen angling that have since been adopted, including catch-and-release and use of artificial lures with single barbless hooks. On the Onon River, a tributary of the Amur River in eastern Mongolia, recreational anglers and local communities have joined together with the help of World Wildlife Fund to form conservation-oriented fishing clubs and establish a taimen sanctuary (450 river kilometres with special rules designed to protect taimen and its habitat). And in north central Mongolia, recreational anglers are spearheading an education campaign called 'Spirit of the River', which educates anglers about proper catch-and-release techniques. Anecdotal reports suggest that current regulations, strict catch-and-release and ongoing angler-led education efforts result in relatively healthy taimen stocks especially compared to areas lacking such regulation and angler participation in conservation.

## Murray cod (*Maccullochella peelii*, Percichthyidae)

*Background, status and threats of endangerment*

Murray cod is the largest Australian freshwater fish, growing up to 1.8 m and weighing over 113 kg (Lintermans *et al.* 2005). It is an iconic apex predator that once supported large commercial fisheries, until 2003, but now only forms the base of an important recreational fishery (Rowland 1989). Murray cod has been categorized on the IUCN Red List of Threatened Species as 'Indeterminate – 1988', 'Endangered – 1994' and as 'Critically Endangered' in 1996 (Wager 1996) and is listed as either vulnerable or threatened in most jurisdictions (Lintermans *et al.* 2005). Murray cod populations have declined by more than 30% since the 1950s. The major factors influencing their numbers include overfishing, poor water quality, competition with introduced fish species and reduced river flow (Rowland 2005). These issues, along with stocking and relocation, habitat regulation and illegal fishing have put immense pressure on their stocks (Lintermans *et al.* 2005). Due to the major population decline, many threat abatement and recovery initiatives have been implemented that aim to bring native fish populations within the Murray Darling Basin back to 60% of the population levels that existed prior to European settlement (see Koehn and Lintermans 2012). While most historical threats to Murray cod stocks have been abated to some extent, overfishing by recreational fishers remains a current pressure. Anecdotal evidence and fisheries data suggest that Murray cod partially recovered in the decade prior to 2005 (Rowland 2005), possibly in response to tighter restrictions on recreational fishing (Lintermans *et al.* 2005).

*The role of anglers in conservation*

A national recreational fishing survey done in 2000 and 2001 suggested up to 77% of the total recreational catch (374 000 Murray cod) were released (Henry and Lyle 2003). Such high release rates were primarily due to bag and size limits, but were also driven by a voluntary conservation measure for larger fish, reflecting the recreational fishing status of this iconic gamefish. Research suggests that post-release mortality is relatively low, ranging from 15% over 4 days to 2% over 5 days (Douglas *et al.* 2010; Hall *et al.* 2011). Murray cod are particularly susceptible to fishing mortality due to being long lived with low natural mortality (Allen *et al.* 2009). The post-release mortality research has, however, suggested best practices for Murray cod (Douglas *et al.* 2010; Hall *et al.* 2011). Management and tournament organizers have also become more conservation orientated with many angling events now catch-and-release. This, along with fairly acceptable compliance rates for bag and size limits, an angler-endorsed closed season on targeting Murray cod during their spawning season and restocking by community fishing clubs demonstrates how anglers are trying to reduce their impacts. Recreational licence fees are also used to fund programmes to assist restocking, habitat restoration, education and compliance. Nevertheless, given that many of the other threats to Murray cod have major restrictions (i.e. commercial fishing and water harvesting), greater restrictions on recreational fishers (i.e. longer closed seasons or catch-and-release only) may be required.

## White sturgeon (*Acipenser transmontanus*, Acipenseridae)

*Background, status and threats of endangerment*

White sturgeon (indeed all sturgeons) possess life-history characteristics (e.g. long lived, low fecundity) that make them susceptible to endangerment, when faced with low levels of mortality (Rochard *et al.* 1990). In 2004, the IUCN categorized white sturgeon as 'Least Concern', although some sub-populations, including those targeted by anglers, are considered more imperilled (Duke *et al.* 2004). Since 1994, their recreational harvest has been prohibited in Canada, whereas in some US jurisdictions, harvest (although often size-based harvest limits and seasonal restrictions) is still permitted. Some of the trans-boundary populations (e.g. Fraser River) are protected from harvest in Canadian waters, but not in the nearby Puget Sound of Washington (Pablo 2012). Despite what the IUCN characterizes as 'substantial' recreational fisheries in some parts of the range, recreational fishing is not regarded as a major threat (Duke *et al.* 2004). Robichaud *et al.* (2006) revealed that immediate hooking mortality was negligible (0.01%) and short-term (72 h) release mortality was low (2.6%; based on a holding pen study), but in general, catch-and-release science remains a priority research topic for governments and NGOs to provide science-based guidelines to anglers (Long 2004). Using population assessment and angler-collected data from 1999 to 2004, Walters *et al.* (2005) reported that there was no direct evidence of cumulative mortality due to repeated capture associated with the Fraser River recreational fishery. Nonetheless, simulation exercises have revealed that fishing mortality rates of 5–8% would halt population growth (Walters *et al.* 2005). Simulations by Jager *et al.* (2002) suggest that removing angling mortality as a threat resulted in the greatest increase in recruitment in reaches of the Columbia River with high angling effort.

*The role of anglers in conservation*

Throughout their range, but particularly in the lower Fraser River, the angling community is an active constituent in white sturgeon conservation. The Fraser River Sturgeon Conservation Society (FRSCS) and one of their celebrity leaders (Rick Hansen) lobbied the British Columbia Ministry of the Environment to create the Sturgeon Conservation Stamp, which is a special licence that must be purchased by all anglers who are going to fish for this species, with the revenue from stamp sales used to support research and conservation. The FRSCS has funded research, developed curriculum and educated school children and the general public, and encouraged its members to collect data while fishing. Indeed, most of the fishing guides in the lower Fraser are equipped with both passive integrated transponder (PIT) tag readers and PIT tagging systems. These guides also participate in routine monitoring and assessment. Volunteer anglers have also been recruited to capture fish for implantation with acoustic telemetry (Robichaud 2012). Moreover, given the challenges in sampling sturgeon in the wild with traditional fisheries gear, IUCN assessments have used angler-based trends in capture success (i.e. angler catch-per-unit-effort of sublegal size fish fell from 0.34 to 0.17 fish per trip between 1985 and 1990; Inglis and Rosenau 1994) to justify listing the subpopulation of the Fraser Region as vulnerable (Down and Ptolemy 2004).

### Atlantic bluefin tuna (*Thunnus thynnus*, Scombridae)

*Background, status and threats of endangerment*

Atlantic bluefin tuna can reach a mass of 650 kg (Collette and Nauen 1983) and are one of the fastest fishes in the ocean. Atlantic bluefin tuna are managed by the International Commission for the Conservation of Atlantic Tunas (ICCAT) as two stocks, an Eastern stock that spawns in the Gulf of Mexico and a Western stock that spawns in the Mediterranean Sea (National Research Council 1994). The stock boundary for Atlantic bluefin tuna follows the 45th W meridian, with each stock having its own fishing quota (National Research Council 1994). Due to overfishing, Atlantic bluefin tuna abundance has been greatly reduced since the 1970s (Anon 2010). In 2010, Atlantic bluefin tuna were proposed for an Convention on International Trade in Endangered Species listing that was voted down by member countries. In 2011, Atlantic bluefin tuna in the western Atlantic Ocean were assessed by the Committee on the Status of Endangered Wildlife in Canada and recommended to be listed as endangered based on four criteria: (i) the current abundance of spawning individuals is the lowest observed; (ii) there has been little sign of population increase in the last 30 years; (iii) the abundance of spawning fish has declined by 69% over the past 2.7 generations; and (iv) overfishing is the cause and it is not clearly reversible (COSEWIC 2011). Fisheries and Oceans Canada subsequently evaluated Atlantic bluefin tuna in the western Atlantic Ocean for listing under the Species at Risk Act (SARA). The listing was rejected based on the following: (i) there is no evidence that their range has been reduced in Canadian waters; and (ii) spawning stock biomass (SSB) has been steady since the 1980s. The proposed recovery target for abundance is to increase SSB, and ICCAT has estimated that this will occur if fishing pressure does not increase (Maguire and Lester 2012).

*The role of anglers in conservation*

Because of their size and strength, Atlantic bluefin tuna are a sought after game fish. There is currently an expanding catch-and-release recreational fishery for Atlantic bluefin tuna that targets mostly giant fish operating in Canadian waters. The fishery is centred in the southern Gulf of St. Lawrence where charter boats access bluefin tuna on day trips. Charter operators are licensed bluefin tuna commercial fishers and operate under science-based guidelines established for the responsible angling and release of bluefin tuna. The post-release mortality rate for bluefin tuna captured and released in an experimental recreationally fishery in the southern Gulf of St. Lawrence was estimated to be 3.4% (Stokesbury *et al.* 2011). Fisheries and Oceans Canada is now estimating the amount of the Canadian ICCAT quota that needs to be accessed for recreational catch-and-release fishing to occur and expand. This fishery has produced positive economic impacts for charter operators and communities and has resulted in heightened public and political awareness of the value of promoting a sustainable bluefin tuna fishery.

## Large coastal sharks

*Background, status and threats of endangerment*

Due to their low intrinsic rates of biological productivity and sensitivity to overfishing, populations of many shark species are highly imperilled, and this group of primitive predators is faced with a level of extinction risk nearly equalling those of large carnivorous mammals (Dulvy *et al.* 2008; Harnik *et al.* 2012). Here, we focus on the three sympatric, endangered shark species that are all apex predators commonly encountered in recreational fisheries (with their associated IUCN Red List status): the lemon shark (*Negaprion brevirostris,* Carcharhinidae, 'Near Threatened'), the great hammerhead shark (*Sphyrna mokarran,* Sphyrnidae, 'Endangered') and tiger shark (*Galeocerdo cuvier,* Carcharhinidae, 'Near Threatened'). All three of these species are found in coastal subtropical (and to some degree temperate) waters throughout the Atlantic Ocean from USA to Brazil, in the waters of some West African countries and in the Pacific Ocean (for tiger and hammerhead, Compagno 1984). These species are slow-growing (age at maturity ranging between 5 and 15 years, Cortés 2000), with gravid females commonly moving into shallow, nearshore waters to give birth to relatively small litters of offspring (fecundity ranging between 4 and 60 pups, Compagno 1984; Cortés 2000). Recent work has shown that both tiger and lemon sharks exhibit minimal changes in their acid-base physiology and reflex performance and retain very high survival (>95%) following capture in commercial and modified recreational gears (Beerkircher *et al.* 2002; Mandelman and Skomal 2009; Gallagher *et al.* 2014). Conversely, hammerhead shark species (including the great and scalloped) show the exact opposite trend driven by extreme physiological disruption and high rates of at-vessel and post-release mortality (Beerkircher *et al.* 2002; Gallagher *et al.* 2014). Despite this wide range of sensitivity to all forms of fisheries capture, the IUCN does not recognize recreational angling as a serious threat to any of these species (IUCN Red List of Threatened Species 2013). Recent legislation passed in the state of Florida (USA) prohibited the harvest of tiger sharks and three species of hammerheads inside state waters. However, due to the documented pronounced stress responses and low survival of hammerheads to fishing gears (Gallagher *et al.* 2014), it is likely that this policy – while beneficial in reducing direct harvests – may not reduce fishing mortality from catch-and-release recreational angling.

*The role of anglers in conservation*

While large shark species carry important social values to recreational anglers (Fisher and Ditton 1993; Lynch *et al.* 2010), interest within the recreational angling community to specifically target sharks has increased, especially given the attention shark angling is getting in the popular media (e.g. television, angling magazines, internet), and their socio-economic value as a renewable resource is only now being realized (Gallagher and Hammerschlag 2011). While interest among recreational anglers in killing sharks seems to be waning (Authors, direct observation) and catch-and-release tournaments are on the rise, until any formal regulations on recreational catch-and-release for large sharks are enacted, anglers themselves hold the fate of sensitive species like hammerheads in their hands. This point is underscored by the notion that charter boat captains often target the largest individuals and, at least in Florida, disproportionately target hammerheads (Shiffman and Hammerschlag in press). Thus, if striving to practice sustainable catch-and-release recreational angling, the onus is on anglers to seek out and base their voluntary decisions on real scientific data on shark stress and survival from fishing events instead of the opinions provided by well-intentioned but sometimes misinformed non-profit organizations and conservation advocates.

## Synthesis of case-studies

The case-studies presented above highlight the fact that endangered fish around the globe in freshwater and marine systems are indeed targeted by recreational anglers. Of particular note is the fact that many of the examples presented represent success stories in that the angling community has become engaged in (if not the driver of) conservation of their target. In some cases, anglers are participating in long-term monitoring programmes which inform conservation plans (e.g. sturgeon), while for Murray cod, funding from angler licence fees is used across a range of initiatives to support recovery programmes. In the Atlantic bluefin tuna fishery, catch-and-release angling revenue for displaced commercial fishers may be a sustainable and economically viable alternative source of income (Stokesbury *et al.* 2011). For taimen and mahseer, angling tourism supports local conservation activities and builds community stewardship for these valuable (both ecologically and economically) endangered species. Similarly, the public is becoming increasingly aware of non-consumptive values of sharks through tourism (Gallagher and Hammerschlag 2011), which extends to non-harvest angling. Nevertheless, a very relevant question is whether angling will impede the recovery of endangered fish populations – or alternatively, what will it do to assist the recovery of an imperilled population. At present, there are few examples where adequate modelling has been carried out to properly address the role of recreational angling in population declines and recovery (see sturgeon modelling; Jager *et al.* 2002; Walters *et al.* 2005; Jensen *et al.* 2009). Similar research activities and decision support tools are needed for other endangered recreationally targeted fish species. Also of interest is the fact that there is no scientific information on the consequences of capture on immediate and post-release mortality for more than half of the species covered here. Without such information, it is difficult to generate species-specific best practices guidelines (or regulations) that promote the survival of released fish (Cooke and Suski 2005) and determine whether such fishing activities yield an unacceptable level of mortality (Coggins *et al.* 2007). Nonetheless, there are some generalities regarding catch-and-release that can be made (see Cooke and Suski 2005) and certainly lack of information on catch-and-release impacts should not be a reason for management inaction when dealing with endangered species. Walters *et al.* (2005) revealed that catch-and-release mortality as low as 5 to 8% would impede recovery of sturgeon, yet results from a catch-and-release study revealed that mortality was indeed much lower (Robichaud *et al.* 2006). This is an essential component of the decision-making process regarding the acceptability of angling for endangered species, yet this does not exist for most species.

## A risk assessment approach

Ecological risk assessment is a decision support tool that evaluates the impacts of various anthropogenic or environmental stressors on ecological components and is an approach which realizes that not all species are affected in the same way when exposed to threats (Suter 1993). Due to the need for precautionary management resulting from the crash of major fish stocks worldwide, ecological risk assessment is becoming an increasingly popular management tool in determining the effects of fishing (Astles *et al.* 2006) and has been applied to various species such as southern bluefin tuna (*Thunnus maccoyyi*, Scombridae; Matsuda *et al.* 1998) and some shark species (e.g. Chin *et al.* 2010; Cortés *et al.* 2010), although the majority of previous work has focused almost exclusively on commercial fishing and by-catch (Gallagher *et al.* 2012).

In the context of recreational angling for endangered species, it is not possible to catch-and-release a fish without eliciting a physiological stress response and inducing some level of physical injury (Cooke and Sneddon 2007). As such, there is always some risk of mortality or sublethal effects (if released) that could manifest themselves as fitness impairments (Arlinghaus *et al.* 2007). In a recent review, Gallagher *et al.* (2012) argued that future risk assessments on imperilled marine species should consider recreational angling as a focal stressor. Although ecological risk assessment is a useful activity for prioritizing conservation planning, it is not always essential or practical. For matters such as the protection of endangered species, there may not be enough time or data to do a formal risk assessment, or at least one that is highly quantitative. While we submit that there would likely be insufficient information to enable a rigorous fully quantitative risk assessment on the impact of recreational angling to endangered fish species such as the ones presented here, its application to assessing recreational angling would be dependent on a number of species-specific factors such as population status, life-history characteristics, behaviour (aggregating, feeding, spawning/mating, migrating), ecological specializations (i.e. diet, habitat suitability) and environmental characteristics (e.g. water temperature), and of course, the predicted impact of recreational fishing (Fig. 2).

To conduct such an assessment, determining which species to include and defining the 'risk' (low-moderate-high) of the threat/stressor in focus (i.e. recreational fishing or just catch-and-release practices) is a key first step. Following these initial steps would be determining and scoring (either quantitatively of qualitatively) the assessment inputs which could include species' distribution, overlap with the stressors (i.e. number of fish caught/effort per square area), measures of biological productivity and the vulnerability to the threat/stressor (physiological sensitivity to capture, rates of post-release mortality). These data can be regressed against one another in two-dimensional space (termed a productivity–susceptibility analysis) and/or each species' values classified according to degree of risk or vulnerability (low-moderate-high) and ranked (or multiplied and ranked); higher rankings generally confer a greater degree of impact and vulnerability to the stressor in play.

While this section was not meant to provide a mechanistic summary of ecological risk assessment (see Hobday *et al.* 2011; Gallagher *et al.* 2012, for reviews), we hope to highlight it as a useful approach to conservation planning of data poor or rare, imperilled species in an applied ecological setting. Lastly, risk assessments related to recreational fishing may not be needed if it is considered within the context of the entire threat assessment and recovery plan which is rather common in developed countries.

We developed a decision tree (i.e. questions with qualitative responses) under which angling for endangered fish should either be allowed/encour-

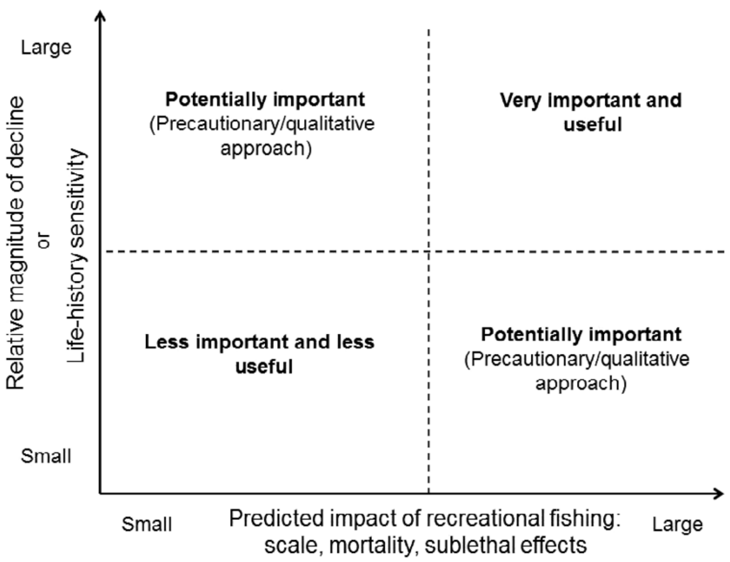


**Figure 2** Framework for determining the importance of assessing the impacts of recreational angling on endangered fish species. Population estimates could be obtained from previously published literature in a specific region, and life-history sensitivity refers to the biological productivity of species, whereby species with delayed ages at maturity and lower fecundity would be more sensitive. In situations where the relative knowledge of certain information may be poor of limited, a precautionary approach may be warranted if the other inputs suggest vulnerability.

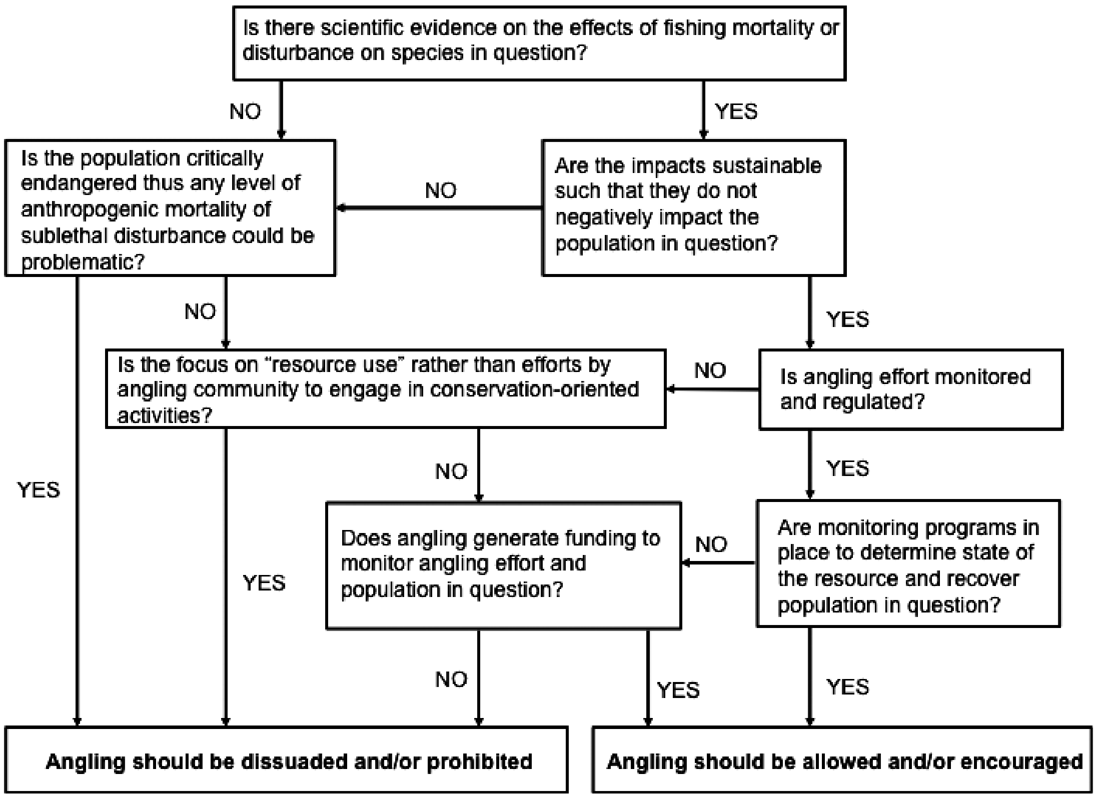


**Figure 3** Decision tree for determining when angling for endangered fish should be allowed/encouraged vs. dissuaded/prohibited.

aged or dissuaded/prohibited (Fig. 3). In most developed countries, regulators (provincial/state/federal governments and international fisheries management organizations) would be left with the decision-making capacity as to when angling would be acceptable. In developing countries, communities or local governments would likely be the primary decision-maker. With the scenarios that we present, we suggest that in most instances, there are multiple factors that would contribute to the decision-making process (also see Fig. 2). Similarly, the formula (i.e. what do you do when the angling community is funding recovery yet the angling is also preventing recovery?) used will depend on the risk tolerance of those making decisions, credibility and reliability of scientific information, knowledge of the angling sector (including effort, catch, mortality, economics) and social–cultural norms and values.

In some cases, there will be legislative instruments that dictate the outcome of the risk assessment. For example, in Canada under SARA, anyone (including anglers) cannot kill, harm, harass, capture, take, possess, collect, buy, sell or trade a species listed as extirpated, endangered or threatened under SARA. This is the case whether the individual member of the species is living or dead and applies to the whole animal and any of its parts. It is therefore illegal for anglers to knowingly target an extirpated, endangered or threatened SARA-listed species. However, in many instances, endangered species co-occur with non-threatened species or even populations. This is particularly the case in the Pacific northwest of Canada and the United States where some Pacific salmon populations are endangered while others are not. Many populations migrate at similar times and through the same path, and there are no easy external ways for anglers to determine whether a captured individual is from an endangered population or one that is healthy. As such, anglers may inadvertently be targeting endangered species, although there is a tendency to mandate release during that period. Clearly, this issue is generally easier to address when an entire species is protected rather than an individual population.

However, there are exceptions. In Quebec, the Ministère des Ressources Naturelles et de la Faune (MRNF) enacted a regulation to prohibit the targeted angling of all redhorse and suckers in regions where the endangered copper redhorse (*Moxostoma hubbsi*, Catostomidae) was present. The reason for the regulation was because it was extremely difficult to distinguish copper redhorse from other redhorse and sucker species (See http://www.mrnf.gouv.qc.ca/english/press/press-release-detail.jsp?id=7511). In this case, an educational campaign alone was deemed to be improbable to succeed; thus, a more sweeping approach was needed to ensure protection for the endangered copper redhorse (*Moxostoma hubbsi*).

## Rethinking the management toolbox

Management strategies for dealing with endangered species targeted by anglers are varied, but in general, there are few formal assessments regarding which management interventions are most suited to controlling angler–endangered fish interactions. Given the focus on the angler–fish interaction in this paper, we will not discuss management interventions such as stock enhancement or habitat restoration (See Cooke and Cowx 2006), but rather concentrate on managing angler effort, catch and mortality. If a risk assessment indicated that angling mortality was negligible and that catch-and-release could be practiced, a prudent approach would be to combine mandatory catch-and-release regulations with other strategies to further mitigate risk of mortality for endangered fish that are angled. If there was a period during the life history of the species for which individuals were particularly sensitive (e.g. parturition, feeding or breeding aggregations), one could adopt seasonal closures (e.g. taimen, Murray cod, large coastal sharks). Another option would be to only permit angling on size-classes, periods or areas (e.g. high predator spots) where fishes are subject to high natural mortality. Area closures (i.e. aquatic protected areas) could be used to create zones where no angling whatsoever is permitted and other areas where only catch-and-release is permitted (e.g. Cooke *et al.* 2006). Codes of conduct (e.g. Arlinghaus *et al.* 2010) and species-specific catch-and-release guidelines (Cooke and Suski 2005) could be developed and embraced as a framework for mitigating potential negative impacts. Furthermore, effort controls are rarely used in recreational fisheries management; however, for endangered species, they could prove effective, especially if disturbance from anglers being present (even if not capturing fish) was a concern.

Informal institutions (e.g. education, outreach) may be as effective as formal regulations when addressing fisheries management issues (Cooke *et al.* 2013), particularly in developing countries, but ideally a combination of strategies would be used. Educational activities and outreach can be carried out independently or in support of formal regulations. In some jurisdictions, formal course training is required to obtain fishing licences. Perhaps for some fisheries, there may be relevance in requiring formal training for anglers in best handling practices prior to granting permission to fish for endangered species. Moreover, direct communication with anglers can be a powerful means of raising awareness and imparting the conservation of endangered species to anglers.

Mandatory requirement of hiring fishing guides/charter captains when targeting endangered fish could also be used as a management mechanism to ensure proper handling, compliance with regulations/best practices, collection of data and control of fishing effort as long as the guides are adequately trained in and committed to conservation best practices. Zwirn *et al.* (2005) describe how guide training on the Kamchatka Peninsula, Russian Federation, evolved from an initial focus on language and service skills to efforts more focused on natural history, stewardship and conservation. To do so required concerted effort by tourist operators, non-governmental organizations and the scientific community to build capacity for eco-tourism (Honey 1999) with the recognition of the value of local/indigenous knowledge. Fishing guide certification programmes would be an effective means of fostering respect for endangered fish, while NGO constituent-based tagging programmes of highly migratory species can also provide an interactive means for fostering awareness and stewardship over large spatial and temporal scales.

## Conclusion

Using a case-study approach, we examined several popular gamefish species targeted by recreational anglers that are also considered ‘imperilled’. When fish are imperilled, no matter what the cause, one must ask whether recreational angling should be halted. Our synthesis revealed that the angling community can become an effective lobby for endangered gamefish which can promote conservation. We provided examples where anglers have participated in monitoring programmes, raising funds for conservation initiatives and leading the way in developing responsible angling practices. However, angling would only be compatible with recovery plans if it did not hinder, but rather helped advance, the recovery and conservation of endangered species. The general public seems to be increasingly aware of the fact that anglers are targeting imperilled species. The harvest of endangered species ('dragon slaying') is becoming viewed as nefarious and taboo. For example, photos showing celebrity Rosie O'Donnell with a dead hammerhead shark that she captured by angling generated immense media attention and public outcry (e.g. http://www.huffingtonpost.com/carl-safina/rosie-odonnell-shark-fishing_b_1204772.html). Beyond engagement and involvement of stakeholders, important indicators of success would be instances when recreational fishing in some way results in the recovery of populations that are imperilled. Population recovery is rarely attributed to a single factor, but there is certainly evidence that recreational anglers have contributed directly to population recovery of endangered fishes (see Granek *et al.* 2008).

For the purpose of this paper, we assumed that angling would inherently have to be catch-and-release to potentially be sustainable, but this can only be known if catch-and-release mortality is quantified and negligible. Certainly, there are some instances where recreational angling is simply incompatible with the recovery of an endangered species (e.g. when a species is critically endangered and when any level of fishing-induced mortality would be unacceptable). We provided a variety of scenarios and approaches that researchers and decision-makers could use to determine the impact of recreational angling and if and when it could be allowed/encouraged vs. dissuaded/prohibited. Factors that should be incorporated into risk assessments and the decision-making process should include the number of anglers, enforcement capability/level of compliance, other protection (e.g. protected areas), potential confounding threats (e.g. pollution, climate change), environmental conditions (e.g. water temperature) as well as the physiological (capture stress), biological (e.g. age at maturity, fecundity), behavioural (e.g. feeding, or breeding aggregation) and ecological (keystone species) attributes of the species.

In keeping with the precautionary approach, it is our assertion that recreational catch-and-release angling for endangered fishes should be limited to species/populations for which scientific evidence demonstrates that such activities are sustainable and that recreational angling and associated conservation activities have *net* positive effects at the population level. In other words, the onus should be placed on the recreational angling community to demonstrate that they are, in fact, advocates and practitioners of best catch-and-release practices and effective proponents of fish and habitat conservation (which has been done effectively by a number of organizations such as Trout Unlimited, the Atlantic Salmon Federation, and Bonefish and Tarpon Trust). Moreover, there is a need to demonstrate that their fishing practices have no negative impact on population recovery of endangered species.

Revisiting our initial question – do the conservation benefits of catch-and-release angling outweigh the costs? Provided that negative biological and ecological impacts of recreational angling on endangered species can be significantly mitigated as well as provide a net benefit to the recovery of endangered fish populations, catch-and -release could be compatible with conservation efforts (also see Granek *et al.* 2008). However, as outlined above (also see Fig. 3), there are a number of scenarios that must be considered to ensure that decisions being made are risk averse and supported by scientific evidence (i.e. risk assessment using biological, ecological and social inputs). Studies explicitly documenting that the catch-and-release of endangered fish generates benefits for those populations are still needed, particularly for shark species which are among the most threatened of marine species. Ideally fish that are endangered will recover to populations levels such that even sustainable recreational angling harvest would be possible (although not necessarily encouraged), and it is our assertion that the angling community is or could be an effective partner in conservation efforts.

## Acknowledgements

Cooke and Stokesbury are supported by the Canada Research Chairs Program, the Natural Sciences and Engineering Research Council of

Canada and the Ontario Ministry of Research and Innovation. Cooke is also a Bonefish and Tarpon Trust research fellow. Danylchuk is supported by the National Institute of Food & Agriculture, U.S. Department of Agriculture and the Massachusetts Agricultural Experiment Station and Department of Environmental Conservation (project number MAS00987). Butcher is supported by the NSW Department of Primary Industries (Fisheries NSW). Hogan is supported primarily by the National Geographic Society and the University of Nevada, Reno. Raghavan is supported by the Critical Ecosystem Partnership Fund and the North of England Zoological Society, Chester, UK. Hammerschlag and Gallagher are primarily supported by the Batchelor Foundation, Guy Harvey Ocean Foundation, Florida Sea Grant, Wells Fargo, the Disney Worldwide Conservation Fund and the RJ Dunlap Marine Conservation Program at the University of Miami.

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