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REVIEWS

Preparing for a changing future in recreational fisheries: 100 research questions for global consideration emerging from a horizon scan

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Abstract Recreational fisheries hold immense ecological, social, and economic value. The management of these fisheries is increasingly important as we move forward in the Anthropocene. Recreational fisheries managers face several challenges as fisheries often involve diverse social and ecological systems comprised of complex feedback and stakeholder motivations and needs. Here, we used a horizon scanning exercise to yield 100 research questions related to recreational fisheries science and management in the Anthropocene. Initial research questions (n=205) were collected from recreational fisheries experts (i.e., stakeholders, managers, researchers) from various sectors (i.e., industry, government, NGOs) and geographic locations (14 countries: Australia, Brazil, Canada, Czech Republic, Germany, Italy, New Zealand, Norway, South Africa, Spain, Sweden, Switzerland, United Kingdom, USA). These questions were subsequently categorized, thematized, and refined by our authorship team, eventually yielding what we considered to be the top 100 research questions of relevance to management of recreational fisheries. The key themes include: human

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dimensions; bioeconomics; resource monitoring and data acquisition; governance; management—regulatory actions; management—stock and habitat enhancement; catch-and-release; impacts of recreational fisheries on populations, communities and ecosystems; threats and sustainability; and angler outreach, education and engagement. It is our intention that this comprehensive and forward-looking list will create a framework to guide future research within this field, and contribute to evidence-based recreational fisheries management and policy.

Keywords Recreational fisheries · Fisheries management · Global fisheries · Research priorities · Biodiversity · Conservation

Introduction

Recreational fishing is defined as "the fishing of aquatic animals that do not constitute the individual's primary resource to meet basic nutritional needs, and are not generally sold or otherwise traded on export, domestic, or black markets (FAO 2012)". Recreational fishing can involve a variety of gear types (including rod and reel, nets, bow and arrow fishing, spearguns) but for the purpose of this paper, we focus solely on rod and reel (i.e., recreational angling). Recreational angling is a popular activity around the globe (Arlinghaus and Cooke 2009). Approximately 140 million recreational anglers exist across the three most industrialized continents (North America, Europe and Oceania; FAO 2012), with estimates of the total number of global recreational anglers around 700 million (FAO 2012). Freshwater recreational fisheries represent the dominant use of wild fish stocks in industrialized countries (Arlinghaus et al. 2007), and coastal marine stocks are often co-exploited for both commercial and recreational purposes (Ihde et al. 2011). Recreational angling plays an important role in supporting local communities of countries with developing economies (Barnett et al. 2016) and has numerous other societal benefits (Arlinghaus and Cooke 2009; Tufts et al. 2015; Freire and Sumaila 2019). Globally, anglers generate approximately $190 billion USD (FAO 2012) in economic activity. Anglers and the angling sector support the conservation and management of the biodiversity on which these fisheries depend (Cowx et al. 2010). However, habitat loss, climate change, overexploitation, and other factors that are pervasive in the Anthropocene threaten the development and sustainability of recreational fisheries and represent significant challenges to their management (Elmer et al. 2017). Beyond environmental threats, there are also socio-economic, cultural, and geopolitical changes that could impact participation in recreational fisheries, such as growing shifting perceptions on animal welfare for sport fish (Arlinghaus et al. 2012) or changes in how people decide to spend

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their leisure time. Moreover, recreational fishing can result in overharvesting and contribute to environmental problems (reviewed in Cooke and Cowx 2006; Lewin et al. 2006). If we are to effectively counteract these and other threats, and improve the inherently difficult task of managing recreational fisheries, then it is essential that researchers generate knowledge that guides the efforts of decision and policy makers involved in recreational fisheries management (Arlinghaus et al. 2019).

Recreational fisheries are considered coupled social-ecological systems that are both complex and dynamic (Arlinghaus et al. 2017), creating unique challenges for recreational fisheries policy makers and managers (Brownscombe et al. 2018). The task of the recreational fisheries manager is not easy in that they often have to make decisions in the face of great uncertainty and operate in an environment where there are often conflicting demands from diverse stakeholders (Cowx et al. 2010). Consensus exists where there is a need to achieve sustainable global recreational fisheries (FAO 2012; Cooke et al. 2019), yet a number of research needs impede realizing that goal. Efforts to identify and address research questions that have the potential to improve recreational fisheries management, practice, and policy are sorely needed. Identification of these needs are essential to supporting the sustainable development and evolution of this important sector.

The horizon scanning "100 questions exercise" is a popular strategy for generating knowledge and identifying research needs (Sutherland et al. 2011). This approach has been used broadly to address emerging issues in a variety of fields and identify research priorities within them (Sutherland et al. 2006; Cooke et al. 2010; Pretty et al. 2010). The exercise is based on collecting and refining questions that are relevant to decision makers within a field. Identifying prominent research concerns within a "100 questions" framework relies on (1) acquiring applicable research question submissions from stakeholders, managers and researchers, (2) refining the submissions down to a list of 100 questions, and (3) using the refined set of questions to direct research efforts. Synthesis of these questions is performed by a panel of experts within their respective fields, as submissions can vary greatly in specificity and relevance. Experts are then able to address issues brought forth by stakeholders in addition to identifying gaps in knowledge that become apparent after the broad topics of concern have been refined. A comprehensive list of research needs related to recreational fisheries has never been generated, whether in terms of expertise, geography, or sector.

Our objective was to identify the 100 most important research questions in the field of recreational fisheries that, if answered, would generate knowledge to support better management of recreational fisheries, including positioning the sector to adapt to a changing world. For the purpose of this exercise, we focused on soliciting questions from diverse stakeholders (including academics, government managers, scientists, the angling industry, angling organizations, and anglers themselves) active in recreational fisheries in marine and/or freshwater environments around the globe.

Methods

We created a basic online survey portal where questions could be contributed and subsequently invited individuals to submit questions via several means. First, a solicitation email was sent to the World Recreational Fishing Conference (held every three years) participant email list. Second, we identified key regional informants (many are co-authors on this paper) and had them distribute the survey using whatever methods they felt would be most relevant for their communities or regions. Next, we used social media (Twitter and Facebook) and online

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fishing fora to further distribute the request for questions. The survey was only available in English. Our target audience was broad; we sought questions from fisheries managers, policy advisors, researchers, anglers, fishing guides, and industry professionals. We received 205 submissions from professionals that spanned 14 different countries (Australia, Brazil, Canada, Czech Republic, Germany, Italy, New Zealand, Norway, South Africa, Spain, Sweden, Switzerland, United Kingdom, USA). Questions concerned both marine and freshwater environments.

The original list of 205 questions was refined by classifying questions into 10 different categories. Questions were then thematized and redundant questions were removed (or grouped). We then assigned each category of questions to at least two co-authors with relevant experience in the respective field (i.e., economics, human dimensions, policy, management, fisheries science, etc.). The questions were then refined and distilled down to a smaller list of questions that were, again, distributed to co-authors. This provided an opportunity to further refine each question with input from our diverse team of co-authors. Assessment criteria focused on making questions "answerable", while ensuring they have the potential to generate new knowledge that can inform policy and practice, or otherwise support the responsible and sustainable development of the sector. Here, we present those 100 questions organized by category and prefaced with a brief introduction.

Human dimensions

A significant part of fisheries management involves managing people's behaviors and expectations (Larkin 1988; Hilborn 2007). Management actions help to reduce stressors to aquatic ecosystems from fishing-related activities and to maintain or enhance the benefits that individuals receive from fishing (Hunt et al. 2013). Whereas human dimensions researchers have long studied fisheries topics (e.g., Moeller and Engelken 1972; Knopf et al. 1973), most human dimensions research efforts have been poorly connected to the needs of, and are poorly communicated to, fisheries scientists and managers (Hall-Arber et al. 2009; Fenichel et al. 2013). Given these problems of managerial relevance and communication, a need still exists for conducting applied research on human dimensions topics. At the most basic level, human dimensions research can help to identify societal views about the legitimacy of and the drivers of participation in recreational fishing (Hunt et al. 2013). Another set of research questions provides foundational information from which managers can predict impacts from fishing by understanding anglers' responsiveness (effort) to changing social and ecological conditions and anglers and managers' abilities to influence catchability and harvest of fish and compliance with the regulations. Finally, human dimensions research can improve our understanding of factors that influence the benefits that people obtain from fishing. The 15 questions on the human dimensions theme balance the need to describe and predict fishing activity and associated benefits with a normative perspective to understand how best to lessen the harmful impacts from recreational fishing and/or increase the benefits associated with it.

1. How can recreational fisheries be managed if the aim is to ensure that all people can access fishing opportunities?
2. How will the population and distribution of anglers likely change over time, and what will these changes mean for recreational fishing effort, angler behaviour (e.g., harvest orientation), regional changes in angler food preferences, and management?
3. What are the most efficient strategies for recruiting, retaining, and reactivating a diversity (e.g., age, gender, and ethnicity) of anglers?
4. What are the drivers and extent of anti-fishing sentiments among different publics and to what extent will this impact the future of recreational fishing?
5. What are the consequences of different fish pain paradigms (e.g., belief that fish feel pain vs skepticism) on the future of recreational fishing?
6. How do angler behaviours change in response to stocking activities?
7. How might the direct changes to climate (such as temperature or altered precipitation patterns) influence fishing opportunity and anglers' behaviour?
8. How do health and safety issues affect anglers' choices of fishing sites?

9. What factors (e.g., angler experience, weather) influence the ability of anglers to catch fish?
10. What factors influence anglers' voluntary decisions to release caught fish?
11. What are the ethical considerations regarding the use of emerging technologies, such as drones (aerial and aquatic), smartphones, and social media, by anglers to collect and share information that could lead to exploitation?
12. How should regulations, enforcement, and/or behavioral nudges be used to foster greater compliance and stewardship activities by anglers?
13. What are the most important factors for achieving angler satisfaction given an increasingly diverse angling community?
14. How could recreational fishing opportunities be promoted to help address issues of health and wellness, in particular among children at risk, people with special needs, and people with post-traumatic stress disorder or those experiencing challenges with mental health?
15. How do we best measure and demonstrate the well-being benefits of recreational fishing?

Bioeconomics

Bioeconomic analysis of recreational fisheries is important for improving recreational fisheries management. The practice also provides an outstanding model system for understanding the allocation of natural capital through time, when the natural capital provides a non-market service. Bioeconomic analysis of recreational fisheries began about 30 years ago (McConnell and Sutinen 1979; Anderson 1983) with simple but informative models that abstracted from many of the challenging features of recreational fisheries. Recent models have focused on angler heterogeneity (Johnston et al. 2010; Fenichel and Abbott 2014a) and regulation (Fenichel and Abbott 2014b; Holzer and McConnell 2014; Abbott et al. 2018). We have identified eleven critical questions in the area of bioeconomics that remain, and require theoretical and empirical investigation. These questions are broad in nature. Some questions are focused on understanding the production process that leads a valuable and enjoyable recreational fishing experience. This involves a lot more than just fish, as pointed out by Boyd and Banzhaf (2007). Other questions explore fundamental economic aspects of the nature of the fishing experience for anglers. Most of the literature treats anglers as autonomous agents (Fenichel et al. 2013), but angling is often a social activity. The list of questions also examines the gap between the current ecological-economic performance of recreational fisheries (many of which are currently open-access or near open-access) and their potential, particularly in the face of environmental change.

16. To what extent does recreational angler surplus derive from the natural capital of fish stocks, the produced capital of fishing gear and boats, and the human capital of angling skill?
17. How do habitat restoration, conservation, ecology and invasive species influence angler surplus and fish stock asset value in a recreational fishery?
18. What is the marginal value of a fish that is vulnerable to recreational fishing (i.e., the contributions of the individual fish and its environment to the likelihood of being caught), and how do sub-lethal effects impact this marginal value?
19. What aspects of fishing trips do anglers actually choose and what decision margins could confound derived benefits?
20. How much impact does congestion or agglomeration (cooperation) among anglers have on the value of an angling trip?
21. How can we differentiate recreational and subsistence fishers in countries where both exist in the same fishery?
22. What is the nature of rent dissipation in an open access recreational fishery?
23. What does it mean to "rationalize" or "optimize" a recreational fishery and what are the distributional or equity impacts of various rationalization schemes?
24. What are the best strategies for ensuring that recreational fisheries development in transitioning economies accrue benefits locally and are managed sustainably in line with local culture and customs?

25. How would a catch-share regulation regime work in a recreational fishery?
26. Will climate and other global change processes increase or decrease angler surplus?

Resource monitoring and data acquisition

Data are an essential element of recreational fisheries science, management, and governance (Krueger and Decker 1999). Data are used to describe the nature and status of the resource and its users, place fisheries within a larger ecological and socio-economic context, and ultimately establish and evaluate management and policy (Cooke et al. 2016). Recreational fisheries are challenging to monitor because they typically emerge from the unreported actions of many individuals who use a variety of means to pursue a resource that is dynamic and diffuse (Lester et al. 2003). The finite nature of monitoring resources means that most fisheries are data-poor in some respect, be it a lack of historical baselines (Rick and Lockwood 2013), or the absence of sufficient information to assess a fishery (Pilling et al. 2009). However, the importance of recreational fisheries to conservation, economics, and global food security is such that information gaps stimulate efficiency and innovation. For example, by estimating sustainable harvest from satellite imagery (Dauwalter et al. 2017) rather than direct measures of lake depth and water quality (Rempel and Colby 1991). There is also a growing interest in digital sources of data such as internet search volume (Carter et al. 2015), online fora (Shiffman et al. 2017), social media (Sbragaglia et al. 2019), and smartphone applications (Liu et al. 2017; Venturelli et al. 2017). The following questions address persistent and emerging challenges associated with recreational fisheries data collection.

27. How do we promote angler engagement in the provision of reliable and accurate catch and effort information?
28. Can technology improve the volume and quality of angler-reported data, and ultimately contribute to more active, waterbody-specific management (e.g., mandatory real-time reporting leading to automated changes to harvest allowances)?
29. How do we ensure the quality of self-reported/voluntary data, and how should these data be used?
30. How do we best account for nonresponse, undercoverage, missing and incomplete information and other biases in recreational fishing data acquisition?
31. How do we assess data-poor recreational fisheries?
32. What monitoring techniques can we use to paint a global picture of recreational fisheries?
33. To what extent can we standardize the means, frequency, and intensity by which we monitor recreational fisheries?
34. How should we monitor effort and catch dynamics, especially in fisheries that are open-access or distributed among many waterbodies?
35. What are the minimum science needs and best management practices for emerging fisheries?
36. Is catch rate a meaningful metric for measuring the success and quality of recreational fishing?
37. How do we future-proof the ongoing collection of reliable and representative recreational fisheries data?

Governance

Governance is a broad term applied to systems of governing and the individuals, groups, and organizations involved in governing processes (e.g., those responsible for steering processes Kooiman et al. 2008). Recreational fisheries governance systems operate within or in connection to larger scale governance systems, such as those of national governments, and can involve elements of cross-boundary management. For example, cross-boundary organizations such as the Great Lakes Fisheries Commission can strongly influence locally-relevant recreational fisheries management decisions in both Canada and the United States. Recreational fisheries governance is also informed by a number of external drivers, including political climate, social climate, and economic policies. Recreational fisheries governance in Germany was strongly influenced by governmental reorganization following the fall of

the Berlin Wall because fisheries management practices differed between East and West Germany (Daedlow et al. 2011). More recently, the directionality of drivers influencing recreational fisheries governance systems and communication among governance actors have also become important to consider. For instance, voluntary or angler-driven support for certain practices can circumvent the need for the institution of top-down formal policies or enforcement methods in some circumstances (Cooke et al. 2013). There are, however, many questions surrounding the role that recreational fisheries governance can play in supporting sustainable management of fish populations and fisheries activities in situations that increasingly require cooperation among governance actors. The questions below highlight some important issues in recreational fisheries governance.

38. What governance processes (e.g., oversight committees, interdisciplinary management groups) are most effective for sustainably managing migratory and pelagic stocks targeted by recreational fishers?
39. Under which circumstances can governance processes that successfully manage sustainable recreational fishing at large scales be effective at smaller spatial scales, e.g., shared boundary, large river systems, or multi-waterbody open access fisheries? If so, in what circumstances?
40. How can fisheries management be structured to have more stability and be less susceptible to the influence of external political and societal pressures?
41. Which governance strategies in highly industrialized countries that are used to maintain sustainable recreational fisheries are applicable to recreational fisheries in less industrialized countries?
42. How can recreational fisheries governance frameworks incorporate values into developmental pressures across fisheries sectors (internal and external) that facilitate sustainable use of fisheries and manage conflict?
43. Are any impacts arising from recreational fishing activity managed by other governance systems (e.g., national or state departments external to fisheries) or are they otherwise unaccounted for?
44. What components of governance systems play the strongest role in supporting sustainability in recreational fisheries?
45. What licensing schemes are most effective and generate benefits to fish populations?

Management—regulatory actions

Harvest regulations represent one of the longest-used tools to protect stocks from overfishing, and are typically used to sustain and improve recreational fisheries (Radomski et al. 2001). The initial use of simple bag limits and minimum length limits has given way to more diverse regulations, such as harvest slot limits, spatial/temporal closures, and catch-and-release regulations to provide catches of large, trophy fish. However, despite decades of trials with various regulations, key uncertainties exist when hypothesizing the outcomes of regulations on recreational fisheries. Impacts of changes in bag and size limits can be difficult to detect (Allen and Pine III 2000), and discard mortality can negate the conservation benefits of harvest regulations and cause recreational fisheries to be inefficient (Coggins et al. 2007). Another key uncertainty is how angler behavior will respond to changes in regulations with regard to their fishing site selection and fishing frequency (Arlinghaus et al. 2013; but see Beard et al. 2003; Beardmore et al. 2011). Despite a diversification of the types of regulations employed, there are still other tools that have received little attention in recreational fisheries (e.g., harvest tags, limited entry, quotas, harvest slots; Lessard et al. 2005; Gwinn et al. 2015; Arlinghaus et al. 2019). Thus, there is a clear need for experimental and adaptive approaches that can elucidate responses of fishers and fish populations to changes in harvest regulations (Pereira and Hansen 2003; Arlinghaus et al. 2017). Key questions needing exploration regarding regulatory actions include:

46. What are the potential strengths and weaknesses of novel regulations like harvest tags, quotas, annual open and closed seasons, or harvest slots?
47. How would the total number of discarded fish deaths be influenced by changes in traditional (size limits, bag limits) and novel regulations

such as harvest tags, harvest slots, quotas, etc.?

48. Under what conditions do spatial and temporal closures effectively reduce fishing mortality and improve sustainability?
49. How does regulation complexity influence the participation, recruitment and retention of anglers?
50. How does fisher behavior (i.e. number of trips, species sought, locations fished) change in response to changes in regulations (i.e. size limits, bag limits, spatial/temporal closures)?
51. Which regulation strategies will allow effective management in the face of increasing human population size and impacts to habitat?
52. How can regulations move away from single-species implementation and into regulations that protect ecosystems and communities?
53. How can management systems be designed to cope with changes in fishing effort?
54. What are the strengths and weaknesses of focusing harvest differentially on certain sizes, such as smaller or larger individuals?
55. What are the best ways to limit effort in specific areas (e.g., national parks, protected areas) or at specific times (e.g., during sensitive life history stages) while still allowing some level of recreational fishing activity?
56. To what extent are common strategies used in recreational fisheries management based on evidence, and what proportion of these strategies are achieving their goal(s)?

Management—stock and habitat enhancement

Recreational fisheries management can broadly target either people (through harvest regulations), fish stocks directly (mainly through stocking and introductions) and/or habitats (through habitat enhancement or protection) (Arlinghaus et al. 2016). Harvest regulations and stocking are probably the most common measures used by recreational fisheries managers (Arlinghaus et al. 2016). Despite substantial progress in our understanding of the relative efficacy of harvest regulations and stocking (e.g., Johnston et al. 2018), many questions remain. Importantly, long-term field studies using before-after-control-impact designs are scarce, limiting our understanding about the conditions and the impacts of harvest regulations, stocking, and habitat enhancement. Moreover, stakeholders often prefer stocking over harvest and other personal regulations (Arlinghaus and Mehner 2005; Arlinghaus 2006; Dorow and Arlinghaus 2012). Additionally, engagement in habitat enhancement can be economically and politically infeasible, creating incentives to continue stocking despite rising awareness that the probability of stocking success is confined to very particular ecological and contextual conditions (Johnston et al. 2018). However, the success of habitat enhancement is uncertain, as demonstrated by the many failed restoration activities in river ecosystems (Roni et al. 2008). The corresponding literature to restore lake ecosystems or coastal sites is particularly scant and full of surprises. For example, despite the often-made assumption that structured littoral habitat should elevate recruitment by reducing natural predation mortality, Ziegler et al. (2018) recently failed to find evidence for this pattern with largemouth bass (*Micropterus salmoides*). It thus remains unclear how and whether habitat enhancement increases fish production in lakes rather than merely redistributing fishes and other organisms from open water to more structured areas without any corresponding increase in production. Moving forward, whole-ecosystem manipulative studies focused on the relative performance of stocking and habitat management would be beneficial in addressing key questions listed below.

57. What are the critical ecological bottlenecks that limit the production of high-quality recreational fisheries, including considerations like sustainable stocks or trophy fish?
58. Does aquaculture have the potential to reduce harvest pressure while benefiting wild-caught species, and if so, what trade-offs affect this balance?
59. What is the relative performance (in social, ecological, and economic terms) of habitat enhancement/restoration, fish stocking and input/output controls, and what are the fundamental trade-offs?
60. What are the desired social, ecological, and economic outcomes of stocking native and non-native fishes/genotypes?

61. Under which conditions can habitat enhancement increase fish production and/or biodiversity rather than merely having aggregation effects?
62. Can stocking-based enhancement be optimized to generate additive ecological and social effects, and if so, how?
63. Which fish habitat configurations generate positive outcomes for recreational fisheries, and how do protected areas fit into these configurations?
64. How can conservation be reconciled with fisheries enhancement, and what are the trade-offs?
65. How does the management of fisheries produce different outcomes in natural versus anthropogenically altered or created ecosystems?

Catch-and-release (C&R)

It is estimated that anglers worldwide release more than half of the fish that are captured (Cooke and Cowx 2006), either as a voluntary practice, or to comply with harvest regulations. Much effort has been devoted to catch-and-release science as a way of maintaining the welfare status of released fish, and to ensure the sustainability of fishing activities (Cooke and Schramm 2007). For example, there have been over 400 such studies with endpoints such as injury, stress, and mortality (Arlinghaus et al. 2007). Research questions still remain, as much of the work has focused on a handful of fish species (Cooke and Suski 2005; Brownscombe et al. 2018) with comparatively little known about the many hundreds of species that are encountered by anglers (see Donaldson et al. 2011). Although some topics (e.g., hook type) have been well explored, there are other aspects of the catch-and-release process related to angler behaviour, the environment, and other factors, that remain poorly studied. Such information is needed to inform regulations and education initiatives (Delle Palme et al. 2016), and to empower anglers to engage in responsible fishing practices (Danylchuk et al. 2018).

66. What methods are the most effective at mitigating barotrauma-related injuries and mortalities?
67. What are the most effective strategies for mitigating post-release predation?
68. What are the longer-term health and fitness consequences (including intergenerational effects and carryover effects) of catch-and-release fishing?
69. What is the survival rate of fish that break off from or escape from recreational fishing gear?
70. What are the minimum data needs to determine if catch-and-release is sustainable for a given species (especially imperiled species)?
71. To what extent will climate change influence sublethal and lethal impacts of C&R, and what can be done to mitigate such effects?
72. What are the methods that yield the most credible and reliable estimates of short- and long-term C&R mortality?
73. To what extent can we make generalizations about fish responses to C&R versus having to do species- and even site-specific studies?

Impacts of recreational fisheries on populations, communities and ecosystems

Recreational fishing is a global enterprise (Arlinghaus et al. 2015, 2016) that can have greater impacts on fish populations and aquatic systems than commercial fisheries (Coleman et al. 2004; Cooke and Cowx 2006; Lewin et al. 2006; Figueira and Coleman 2010; Hyder et al. 2014). The unique characteristics of recreational fisheries, which may include the specific targeting of trophy specimens (Shiffman et al. 2014), the continuation of fishing past the point of economic sustainability (Holland and Ditton 1992; Fedler and Ditton 1994), and catch-and-release, play a role in how they impact the abundance, size structure, and evolution of fish populations (both through direct and indirect selection pressure). Besides the effect of harvest, recreational fishers have an impact on aquatic ecosystems through their general activities, such as boating and littering, and their more specific activities, such as the legal or illegal translocation of fishes and live bait. Despite the myriad of complex impacts, when compared with commercial fisheries, the effect of recreational fisheries on aquatic ecosystems are relatively poorly understood (Cooke and Cowx 2006). To facilitate the improvement of our

knowledge, a strategic research focus is required. This will provide managers with the information required to promote recreational fisheries activities that will maintain the integrity of ecosystems.

74. Relative to commercial fisheries, how likely is recruitment overfishing and substantial erosion of fish age/size structure via recreational fisheries?
75. How can different recreational harvest regulations influence the reproductive output of fish populations?
76. What are the mechanisms and consequences of recreational fisheries-induced evolution of fish life history, behavior, and physiology?
77. How many fish populations have been extirpated primarily due to overexploitation by recreational fisheries, and what circumstances led to these losses?
78. How do recreational fisheries influence the resilience of fish populations and ecological communities to the impacts of climate change?
79. How can recreational fisheries positively or negatively influence threatened indigenous fish populations and biodiversity outcomes?
80. How do harvest recreational fisheries alter the structure and function of fish communities (e.g., via trophic cascades associated with removal of top predators), and how does this compare to catch-and-release fisheries?
81. What is the role that recreational fisheries can play in driving trait-mediated effects and how can these alter food web interactions?
82. How does the transmission of fish diseases and pathogens by recreational fishing activities influence fish communities, and what can be done to reduce this?
83. How does recreational fishing alter habitat and influence ecosystem integrity, and what role can recreational fisheries play in improving ecosystem integrity?
84. What are the direct and indirect consequences of the introduction/translocation of fauna on aquatic ecosystems, and what is the most effective way to limit these translocations?

Threats and sustainability

Recreational fisheries depend on the ability of healthy fish populations to produce a harvestable surplus available to anglers. Many of the fishes that are targeted in recreational fisheries face various threats, including climate change, hydropower regulation, other habitat alterations, migration barriers, water abstraction, aquaculture activities, pollution, introduced species, and overfishing (e.g. Lucas and Baras 2001; Kerr et al. 2009; Forseth et al. 2017; Paukert et al. 2017). Commercial and recreational fisheries may compete for the same fish resources, though both sectors are susceptible to overfishing and unwanted/uncontrolled depletion of the fish resource (FAO 1994; Cooke and Cowx 2006). Fisheries science has contributed to our increased understanding of the threats to fish populations, and contributed to knowledge-based management. However, recreational fisheries around the world target a variety of fish species in diverse freshwater and marine habitats (e.g., Cooke and Cowx 2004; Olds et al. 2018), and there are still knowledge gaps related to the different threats and how to mitigate them. Addressing new and emerging threats require knowledge generation and underline the need to develop strategies for managing data-poor fisheries.

85. What is the definition of recreational fisheries sustainability across regions and cultures?
86. How do climate change and invasive species impact marine and freshwater habitats and ecosystems, fish species, and the surplus that supports recreational fishing?
87. To what extent do habitat alterations, such as hydropower regulation, migration barriers, and water extraction, impact recreational fisheries?
88. How do aquaculture activities impact wild fish populations and, ultimately, recreational fishing?
89. How do commercial harvest and bycatch impact recreational fishing and vice versa?
90. How can we identify strategies that effectively promote sustainability in recreational fisheries that are not adequately researched or managed?
91. What is the scope, scale, and consequence of illegal, unreported and unregulated (IUU) recreational fisheries?

92. Are humans being exposed to harmful levels of toxins (e.g., metals, microplastics) when they consume angled fish or could they be in the future?
93. What are the best approaches (given language barriers, variable rates of literacy) for sharing fish consumption advisories for angled fish in a diverse yet increasingly digital world?

Angler outreach, education and engagement

Much effort has been devoted to various outreach and education initiatives in an effort to engage anglers in responsible and sustainable fishing practices (Granek et al. 2008). Beyond ensuring compliance with regulations (Cooke et al. 2013), such engagement is key for obtaining support for new fisheries management initiatives (Dedual et al. 2013) and for ensuring that voluntary activities (such as voluntary catch-and-release, sanctioning; see Guckian et al. 2018) yield meaningful biological outcomes (e.g., Delle Palme et al. 2016). Indeed, we are in a new era where it is essential to "work with, not against" (sensu Mannheim et al. 2018) anglers and other key partners (including angling NGOs and the angling industry). We are only recently starting to understand the consequences of inadequate or ineffective communication and engagement with the angling community (Dedual et al. 2013). There are many outstanding questions regarding angler outreach, education, and engagement that need to be addressed.

94. What are the current barriers that impact recreational fishers from receiving the most up-to-date and scientifically-validated best practices?
95. What role does the angling industry play in the dissemination of responsible fishing practices to their customers (i.e., recreational anglers)?
96. What are the best ways to share information on responsible and sustainable fishing practices with recreational fishers that lead to long-term improvements in fisher behavior and discourage bad behaviours?
97. What are the ways to best equip anglers with the ability to engage in sanctioning or nudging that yields positive conservation outcomes?
98. Given the increasing global nature of recreational fisheries, which cultural, ethical, and philosophical challenges might limit the adoption of best practices regardless of science-based evidence?
99. How might training courses (voluntary or mandatory) focused on responsible fishing practices lead to improvements in fish welfare and survival?
100. What engagement and co-management strategies lead to the highest levels of recreational fishers' satisfaction?

Conclusion

After identifying a need for broader guidance for recreational fisheries around the world, our group applied the horizon scan approach to identify 100 questions that are important to recreational angling. The resulting 100 questions were a distillation of the original submissions and focused on creating answerable and attainable research objectives. These questions can be used to direct research efforts that supply managers and decision-makers with credible, science-based evidence. The scope of the questions ranges from specific to broad, though all are focused on addressing concerns across the ten categories that were evaluated by diverse professionals in their respective fields.

Although we intended to reach as broad an audience as possible, we acknowledge that the solicitation of input for this exercise had certain limitations. The distribution of the survey was limited to our network of regional informants, to the contacts within our social networks, and to the lists of conference attendees. We also understand that the distribution of the survey in English may have limited the potential for soliciting contributions. Moving forward, our hope is that this exercise will reach additional members of the recreational fisheries community who may have important input with respect to future research directions.

Application of this "categorical" approach in future will allow researchers to find knowledge gaps within their scope of expertise by examining the list of broader questions. This allows scientists (of all forms—spanning the natural and social sciences and

humanities) to create manageable projects, employ realistic goals and generate knowledge that supports policy makers and practitioners. This list could support the development of globally applicable management strategies that are adaptable to both established and emerging recreational fisheries. Addressing research concerns brought forward by this exercise increases the potential to support sustainable recreational fisheries which benefit economies, human well being, food security and ecosystem services among many other things—the goal of contemporary recreational fisheries management (Arlinghaus et al. 2019).

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