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The future of recreational fisheries: Advances in science, monitoring, management, and practice

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ABSTRACT

Recreational fisheries (RF) are complex social-ecological systems that play an important role in aquatic environments while generating significant social and economic benefits around the world. The nature of RF is diverse and rapidly evolving, including the participants, their priorities and behaviors, and the related ecological impacts and social and economic benefits. RF can lead to negative ecological impacts, particularly through overexploitation of fish populations and spread of non-native species and genotypes through stocking. Hence, careful management and monitoring of RF is essential to sustain these ecologically and socioeconomically important resources. This special issue on recreational fisheries contains diverse research, syntheses, and perspectives that highlight the advances being made in RF research, monitoring, management, and practice, which we summarize here. Co-management actions are rising, often involving diverse interest groups including government and non-government organizations; applying collaborative management practices can help balance social and economic benefits with conservation targets. Technological and methodological advances are improving the ability to monitor biological, social, and economic dynamics of RF, which underpin the ability to maximize RF benefits through management actions. To ensure RF sustainability, much research focuses on the ecological aspects of RF, as well as the development of management and angling practices that reduce negative impacts on fish populations. For example, angler behavior can be influenced to conform to conservation-minded angling practices through regulations, but is often best accomplished through growing bottom-up social change movements. Anglers can also play an important role in fisheries monitoring and conservation, including providing data on fish abundance and assemblages (i.e., citizen science). The increasing impacts that growing human populations are having on the global environment are threatening many of the natural resources and ecosystem services they provide, including valuable RF. However, with careful development of research initiatives, monitoring and management, sustainable RF can generate positive outcomes for both society and natural ecosystems and help solve allocation conflicts with commercial fisheries and conservation.

1. Introduction

Recreational fisheries (RF) are defined as the fishing of aquatic animals that do not constitute the individual's primary source of nutrition and are not sold or traded on any market (FAO, 2012). Recreational fishing is a highly popular activity worldwide, with at least 220 million people participating and capturing billions of fish every year (Arlinghaus et al., 2015; Cooke and Cowx, 2004; The World Bank, 2012). In industrialized nations, it is now considered to be the dominant extractive sector that exploits freshwater fish stocks and a major component of the exploitation of coastal and marine resources (Arlinghaus et al., 2002; Coleman et al., 2004; Hyder et al., 2018). Recreational fisheries generate substantial social and economic value (Hyder et al., 2018; Rudd et al., 2002; Tufts et al., 2015) and also play a significant role in aquatic conservation. On one hand, RF exploit fish stocks, which can negatively impact both fish populations and aquatic environments (Cooke and Cowx, 2004; Lewin et al., 2006). Most prominently, overfishing has been cited as a major cause of global fish population declines, often impacting entire aquatic ecosystems (Pauly et al., 1998; Post et al., 2002). On the other hand, RF often produce positive conservation effects by generating funding for conservation initiatives and connecting people with resources, engendering concern for the conservation of fish and the habitats that support them (Arlinghaus and Cooke, 2009; Cooke et al., 2013; Cowx et al., 2010; Granek et al., 2008; Tufts et al., 2015). Thus, diligent management is necessary to generate a safe operating space for fisheries that balances social and economic benefits with conservation targets and solves allocation issues in mixed commercial-recreational fisheries (Abbott et al., 2018; Arlinghaus and Cooke, 2009; Carpenter et al., 2017; Hyder et al., 2018; Johnston et al., 2010).

Natural ecosystems and biological communities are inherently complex, as are the RF user groups, and their related socio-economic systems (Panayotou, 1982). Hence, effective management of these complex social-ecological systems (Arlinghaus et al., 2017a,b) must be multi-faceted and take due account of the large variability in values and governance systems designed to address fisheries in various regions around the globe. To that end, understanding the user groups in terms of demography, interests, opinions, and behaviors ensures maximal social benefits and participation (Johnston et al., 2010). Angler behaviors also determine how they interact with fish and their environment, which ultimately determines the degree of environmental impacts across aquatic landscapes (Carruthers et al., 2018; Hunt et al., 2011; Kaemingk et al., 2018; Matsumura et al., 2017; Wilson et al., 2016). For this reason, research that characterizes common angling practices and

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their impacts on fish provides an essential basis for both monitoring fisheries impacts and developing techniques that minimize them. This is particularly important given that catch-and release (C&R), either practiced voluntarily or as a by-product of harvest regulation such as size-based retention limits, is becoming increasingly prevalent in RF (Arlinghaus et al., 2007). For example, in Canada, over 60% of captured fish are released due to a combination of harvest regulations and conservation ethics of anglers (Brownscombe et al., 2014a). Similar proportions of fish are released in European marine fisheries as well (Ferter et al., 2013). Whether C&R is legally mandated or voluntary, an important assumption of this practice is that released fish survive with limited fitness impairments. Hence, development of conservation-minded angling practices that minimize impacts on fish is paramount to achieve sustainable fisheries (Brownscombe et al., 2017). Monitoring of participation rates (Arlinghaus et al., 2015) as well as the social and economic benefits generated from RF is also important for establishing the value of RF (Parkkila et al., 2010). This information is essential for the governance of RF as it provides the basis for the appropriate allocation of resources (Abbott et al., 2018; Costanza et al., 1997).

Recreational fisheries are complex social-ecological systems that are evolving rapidly (Arlinghaus et al., 2017a,b,2016a,b; Ward et al., 2016). Under this paradigm, macroscale outcomes like sustainable or overexploited RF emerge from tightly coupled social, ecological, and management feedbacks that are happening first and foremost at the local micro-level (Arlinghaus et al., 2017a,b; Matsumura et al., 2017). For this reason, research, monitoring, and management must also evolve its techniques and approaches rapidly to capture these diverse and interdisciplinary topics to achieve sustainable RF and environmental conservation (Elmer et al., 2017). This special issue on recreational fisheries includes diverse works from authors around the world focusing on understanding the social, ecological, or management processes that influence RF outcomes based on key innovations presented at the 8th World Recreational Fisheries Conference (WRFC) held in Victoria, Canada, in 2017. This was the largest of the eight WRFCs in terms of attendees, attracting 398 delegates from 20 countries who delivered five keynotes, 227 contributed talks and 40 contributed posters. The conference was hosted by the Freshwater Fisheries Society of British Columbia (BC), in cooperation with the Sport Fishing Institute of BC and was themed: "*BALANCING VALUES: The Future of Recreational Fishing Around the World*". The conference included three symposia:

- Understanding Angler Behaviour Through Human Dimensions and Economics Research
- Use and Challenges of Catch-and-Release in Recreational Fisheries Management
- Recreational Fishers Driving Fish Habitat Outcomes

Here we summarize the insights and ongoing developments in recreational fisheries that emerged during the conference and in the articles included in this proceedings issue in *Fisheries Research*, which we discuss under the themes Characterizing participation, Characterizing social and economic value, Advances in monitoring, Stock enhancement, Minimizing biological impacts, and Transferring best angling practices to anglers. We then discuss the implications of the summarized work for the future of recreational fisheries.

2. Characterizing participation

To accomplish effective management of recreational fisheries as coupled social-ecological systems, characterizing and monitoring the participants, their interests, values, behaviors, and economic contributions are essential. Globally ~11% of people participate in RF (Arlinghaus et al., 2015; Arlinghaus and Cooke, 2009; Cooke and Cowx, 2004; Hyder et al., 2018). However, macroscale participation data are lacking for many countries and regions. While there is little participation data in many developing countries, there is evidence to suggest that RF are growing rapidly due to shift from subsistence fisheries to recreational, particularly in the form of tourism (FAO, 2012; Gupta et al., 2015; Smith et al., 2005). In developed countries, fishing for leisure is also growing in some areas, which is also reflected in the increased prevalence of C&R (in addition to increased harvest regulations; Cooke and Cowx, 2004). Yet, in some regions overall RF participation is declining. For example, nationwide in Canada participation declined 33%, with direct expenditures down by 42% from 1985 to 2010 (Brownscombe et al., 2014a).

The motivations behind angler participation are diverse; they can be broadly categorized into psychological, experiential, social, or challenging/skill development (Fedler and Ditton, 1994). In industrialized countries, participation rates are negatively correlated with proxies of urbanization and the size of the economy (Arlinghaus et al., 2015). Other commonly cited causes for participation decline in RF around the world include education levels, changes in the demographic composition of societies, fishing quality, cost, regulations, changes in social embedding of recreational fishing within societies, and ethical concerns (Aas, 1996; Arlinghaus et al., 2015; Fedler and Ditton, 2001; Murdock et al., 1992). Given the varied trends in RF participation rates worldwide, the factors that influence participation are relevant to the socioeconomic benefits of fisheries as well as managing biological impacts (see Characterizing social and economic value and Minimizing biological impacts below).

In response to a major decline in RF participation in Taupo, New Zealand, Dedual and Pickford, (2018) explored potential causes. They found license cost was a key factor influencing participation rates, along with fishing quality and the unemployment rate of the region. Similarly, Parkinson et al. (2018) found participation costs, including licensing, gas, and currency exchange, were important drivers of angler effort in stocked rainbow trout lakes in British Columbia, Canada. Due to the influence of financial costs on angler participation and effort, surveys of angler willingness to pay can provide valuable information for effective management. For example, Blicharska and Rönnbäck, (2018) identified critical thresholds in angler willingness to pay relative to potential fishing quality in anglers in Sweden, which may guide fisheries management practices to optimize participation and socioeconomic value. Fishing quality can also be an important aspect of angler participation (Dabrowska et al., 2014), therefore understanding angler interests and priorities is also important to manage fisheries effectively (Dabrowksa et al., 2017; Ward et al., 2013). Curtis, (2018) examines a situation where there is conflict within a multi-species fishery in Ireland. In characterizing angler preferences, he found a more nuanced and less bipartisan inclination than previously realized, suggesting that control measures on certain species based on vociferous public campaigns may not necessarily maximize overall angler participation or satisfaction.

3. Characterizing social and economic value

Recreational fisheries generate social benefits by providing an accessible leisure activity and a source of food for personal consumption, with related benefits to the participants, including exercise, reduced stress, and social bonding, contributing to improved physiological and psychological well-being (Arlinghaus et al., 2002; Fedler and Ditton, 1994; Griffiths et al., 2017; Hughes, 2014; Parkkila et al., 2010; Tufts et al., 2015). In addition to social benefits, knowledge of the economic value on natural resources can also provide impetus for governments and motivate policy support to protect and conserve fish and their habitats. For example, knowledge of the economic value of C&R bonefish (*Albula vulpes*) fisheries in The Bahamas is playing an important role in converting a historical subsistence fishery to nearly entirely C&R recreational fishery, as well as improving bonefish habitat protection (Danylchuk et al., 2008; Fedler, 2013; Sherman et al., 2018). Characterizing the economic value of RF is also essential for prioritizing resource use. For example, Marine Protected Areas (MPAs) are a growing conservation strategy in nearshore marine ecosystems around the world (Agardy and Tundi Agardy, 1994). In some cases, no-take (C&R) fishing is allowed in MPAs, while in others it is prohibited (Agardy et al., 2003; Cooke et al., 2006). C&R fishing may or may not be appropriate for an MPA depending on various characteristics of the ecosystem, socioeconomics of the region, and biological impacts of the fishery – understanding these characteristics is therefore essential for making informed management decisions (Danylchuk and Cooke 2011). Mann et al. (2018) provide an example of the biological impact of C&R in a longstanding MPA in South Africa. They conclude that under a strictly controlled regulatory framework, maintaining biological integrity and increasing the economic benefits of the MPA are possible. Under this same theme, Blicharska and Rönnbäck, (2018) studied expenditures and preferences of the mixed sea trout *Salmo trutta trutta* fishery in Sweden where commercial, recreational, and tourist fishers jointly use a common resource. They found large differences in preferences, catch and harvest tendencies, and willingness to pay for increased license fees between these different typologies, which provides some insight on developing effective co-management practices for this important mixed fishery.

Despite the importance for RF governance and management, there is generally a dearth of socio-economic information for RF in most regions and particularly in the developing world. However, much descriptive research is actively addressing this knowledge gap (Pitcher et al., 2002). Pita et al. (2018) explore the economic, social, and ecological attributes of marine RF in Spain estimating ~€100 million in annual expenditures. Southwick et al. (2018) estimated that 600,000 marine recreational fishers spent NZ$946 million supporting marine around 8000 jobs in New Zealand. These studies provide a baseline framework for RF in these regions and will play a key role in the regional development of valuable and sustainable fisheries.

4. Advances in monitoring

Monitoring RF activity, including participation, effort, compliance, catch and harvest rates, involves significant logistical challenges due to the large spatial and temporal scales of RF (Hyder et al., 2018). This can result in low precision or accuracy in estimates of fisheries metrics such as harvest, which can inhibit effective fisheries management (Pollock et al., 1994). To overcome these challenges, much ongoing monitoring and research efforts are developing and applying innovative techniques and approaches. Ma et al. (2018) compared multiple approaches to survey fishing effort, as well as fish catch and harvest rates in Hawaii, including point intercept, household telephone, roving shoreline, aerial fishing effort, and mail surveys. This provided a comprehensive estimate of RF dynamics and an assessment of various survey method biases, consistencies, and discrepancies. Similarly, Holdsworth et al. (2018) tested multiple approaches to monitoring fish harvest rates in New Zealand, involving three concurrent survey methods that included both on- and off-site surveys, providing higher confidence in harvest estimates. van Poorten and Brydle, (2018) assess the use of remote traffic counter technology to estimate fishing effort on a lake in British Columbia, Canada. They found this technology is a viable, low-cost and effort method to track fishing effort, but requires concurrent measures of fishing and non-fishing traffic such as motion-detecting cameras or creel surveys and is best suited to systems where the majority of traffic is fishing-related. Smartphone applications also represent a valuable new technology enabling remote collection of angler participation, and behaviors including effort, catch, and harvest (Jiorle et al., 2016; Papenfuss et al., 2015; Venturelli et al., 2017). This approach comes at a low cost and effort relative to other techniques such as conducting surveys, but has its own set of challenges related to data-quality standards, angler recruitment and retention, and integration with ongoing fisheries programs (Venturelli et al., 2017).

Monitoring the level of angler compliance is a critical component in fisheries as it provides an indicator of the efficiency of the management system (Arias et al., 2015; Johnston et al., 2015; Sullivan, 2002). Due to the difficulty in obtaining accurate compliance information, most compliance research has relied on angler interviews and have implemented "less direct" questioning methods, such as the random response technique (Blank and Gavin, 2009; Warner, 1965), when asking anglers sensitive questions, such as whether they break the angling regulations. Bova et al. (2018) evaluated a range of techniques aimed at obtaining truthful compliance information from angler interviews by interviewing anglers that were observed covertly flouting the fishing regulations. They found that traditional methods to reduce social desirability bias and non-response bias, including the random response technique (Warner, 1965) performed poorly in estimating compliance and suggested an alternative Ballot Box method, which has been used in health sciences for understanding sensitive sexual behavior (Gregson et al., 2002).

In addition to monitoring recreational fishing activities, advances are also occurring in fish population monitoring. Florisson et al. (2018) test a citizen-science approach to monitoring reef fish fauna on artificial reefs in Australia using a system named Reef Vision. They conclude this is a viable approach to monitoring reef fish communities, while significantly reducing the amount of effort and resources required by scientists. Støttrup et al. (2018) demonstrated the potential for use of citizen science to generate geo-spatial data on coastal fish assemblages that could be used to support management. Elliot and Russello (2018) test a set of advanced molecular markers to accurately differentiate between advanced genetic hybrids of stocked sockeye salmon (*Oncorhynchus nerka*) and wild resident kokanee salmon, enabling improved assessment of reintroduction efforts and wild fish population status.

5. Stock enhancement

Supplementing current RF or creating new ones by releasing hatchery-raised or wild fish captured elsewhere into aquatic ecosystems (i.e., fish stocking) dates back to the early 19th century, and is still a pervasive fisheries management tool (Arlinghaus et al., 2016a,b; Pister, 2001). Although this practice often successfully produces RF opportunities (e.g., in put-and-take fisheries), it can have a suite of negative biological impacts including the spread of pathogens (e.g., Frazer, 2009), a reduction in the genetic diversity of wild populations (Araki and Schmid, 2010; Laikre et al., 2010) and an increase in the resource competition with wild fish without the benefit of increased reproductive capacity (often by design or due to a lack of life skills; e.g., Lorenzen et al., 2012; Milot et al., 2013). Despite potential negative biological effects associated with stocking, many management agencies continue stocking efforts, often at a major financial cost, to maintain RF opportunities. In some countries, particularly in central Europe, private organizations are implementing stocking programs (Arlinghaus, 2006; Daedlow et al., 2011; Fujitani et al., 2017). Harrison et al. (2018) discuss the multiple benefits that can arise from voluntary, non-government stocking programs, which extend beyond fishing opportunities to include social, psychological, and conservation benefits of private involvement in aquatic conservation.

Given the financial costs, limited managerial budgets, and potential ecological impacts of fish stocking, discerning optimal stocking practices is essential to maximize RF opportunities and minimize biological impact. To this end, much ongoing research is aimed at understanding the factors that influence stocking success, both in terms of fish growth and survival as well as catch per unit effort and angler effort responses (Hühn et al., 2014; Mee et al., 2016). Varkey et al. (2018) explored how landscape characteristics and stocking densities influence the growth of rainbow trout (*O. mykiss*), providing key insights into how stocking practices, in terms of where and how many fish are stocked, can be optimized based on fisheries goals. This may include maximizing the number or the size of fish available for anglers. Cassinelli and Meyer, (2018) examined how a similar suite of factors influence angler capture rates in rainbow trout in Idaho. They found that stocking larger trout in smaller waterbodies at lower elevations resulted in the greatest angler return rates (corresponding with stocking models), yet these systems require more frequent stocking. Parkinson et al. (2018) showed that angler effort was higher when triploid (i.e., genetically altered sterile) rainbow trout were stocked, when compared with diploid individuals. This was thought to be due to higher growth and survival of triploid individuals and associated improvements in catch-based fishing quality. As triploid individuals are sterile, the goal of this stocking approach was to create a 'put-and-take' fishery, with the added benefit of reduced risk in genetic deterioration of wild fish stocks.

6. Minimizing biological impacts

Recreational fisheries can have numerous detrimental biological impacts, including general ecosystem disturbance and pollution, introduction of invasive species, disturbance of wildlife and habitats, or direct impacts of overexploitation on fish populations (Altieri et al., 2012; Cooke and Cowx, 2006; Lewin et al., 2006; Post et al., 2002; Venohr et al., 2018). Historically, overexploitation via fish harvest has been a major cause of recreational fishing-induced population declines (Lewin et al., 2006; Post, 2002). Further, by selectively targeting larger individuals of the population, RF can elicit changes in fish population structure and phenotypic traits that exacerbate fisheries declines and inhibit population recovery (Arlinghaus et al., 2010; Gwinn et al., 2015; Heino et al., 2015; Hessenauer et al., 2018; Law, 2007; Post, 2013). Therefore, legal restrictions are placed on fishing effort (both harvest and C&R activity) in the majority of current RF including limitations on the number and size of fish harvested, seasonal and spatial closures, and allowable gear types (Cox et al., 2002; Johnson and Martinez, 1995; Wilde et al., 2003). Yet, because fisheries are often managed at regional scales, effort is rarely regulated at the individual fishery level (Carruthers et al., 2018; Lester et al., 2003; Mee et al., 2016; Post, 2013; Post et al., 2003). Further, recreational anglers often maintain high levels of fishing effort when fish abundance and fishing quality decline (Johnston et al., 2010; Post, 2013). Fishery vulnerability to collapse therefore depends on a complex set of factors related to social, economic, and ecological attributes, which influence the optimal fisheries management strategies (Johnston et al., 2015, 2010; Post et al., 2003).

Considering the negative population impacts of selective harvest, there is growing evidence that protecting larger members of the fish population with more size-balanced harvest results in improved population size, age structure, resilience to population decline, as well as greater numbers of fish harvested and improved 'trophy' C&R fishing opportunities (Arlinghaus et al., 2010; Gwinn et al., 2015; Law et al., 2012; Law and Plank, 2018; Pierce, 2010). This can be accomplished in some cases by limiting allowable harvest (Rypel, 2015), or imposing harvest slot limits (i.e., minimum and maximum fish size allowable for harvest) opposed to the traditional approach of minimum-size limits (Arlinghaus et al., 2010; Gwinn et al., 2015; Law and Plank, 2018; Pierce, 2010). However, importantly, the benefits of harvest regulations can be undermined by high fishing effort, illegal harvest, or negative impacts of C&R (Ayllón et al., 2018; Hessenauer et al., 2018; Johnston et al., 2015; Miranda et al., 2017; Post et al., 2003; Sullivan, 2003).

Due to harvest regulations and growing conservation ethics of anglers, C&R is a growing conservation strategy in most RF (e.g., Arlinghaus et al., 2007; Brownscombe et al., 2014a,b; Cooke et al., 2015; Ferter et al., 2013), with the implicit assumption that fish will survive and experience limited fitness consequences. However, C&R can cause physiological stress and injuries to fish that can result in reduced biological fitness or post-release mortality due to the energetic demands of physiological recovery, or behavioral impairment that may reduce reproductive success or increase susceptibility to predation (reviewed in Arlinghaus et al., 2007; Cooke and Suski, 2005; Lewin et al., 2006; Siepker et al., 2007). Therefore if fishing effort and C&R impacts are high, C&R can fail to function as a conservation strategy, resulting in similar negative impacts to overharvest (Arlinghaus et al., 2007; Cahill et al., 2018; Coggins et al., 2007; Hessenauer et al., 2018; Johnston et al., 2015; Post et al., 2003). The extent of these negative impacts varies greatly due to the interactions between angler behavior, fish species characteristics, and environmental conditions. Anglers have control over when, where, and how they fish, and can therefore minimize their impact by altering their behavior to conform to scientifically based 'best angling practices' (reviewed in Brownscombe et al., 2017). Best angling practices depend on species and environmental characteristics, but general recommendations including reducing fight times, air exposure periods, using hooks that minimize injury (e.g., appropriate sized circle hooks for the species), and avoiding higher temperature extremes.

Ongoing research on the impacts of C&R are continuing to expand our knowledge of best angling practices. Importantly, although hundreds of studies have been conducted on this topic (reviewed in Arlinghaus et al., 2007; Brownscombe et al., 2017; Cooke and Schramm, 2007; Cooke and Suski, 2005; Pelletier et al., 2007), most have focused on only a few recreationally angled species (Cooke and Suski, 2005). Given that the impacts of RF can be diverse and dependent on species and environmental conditions, assessments of diverse species around the world are necessary. Lennox et al. (2018) examined the impacts of C&R on the post-release behavior and survival of arapaima (*Arapaima* cf. *arapaima*), an obligate air-breathing species found in freshwater ecosystems of South America. They revealed that breathing air post-release is an integral part of arapaima survival, which is a rare phenomenon that is an essential consideration for the sustainability of this fishery.

In expanding the breadth of knowledge of C&R angling practices, considering real-life recreational fishing conditions, angler behaviors, and fish characteristics are also important. For example, there have been numerous studies on the impacts of C&R practices on rainbow trout (*e.g.,* Ferguson and Tufts, 1992; Meka, 2004; Schwabe et al., 2014), yet the majority have been on captive fish of hatchery origin. Twardek et al. (2018) explored the impacts of C&R *in situ* for wild steelhead (i.e., rainbow trout with an adult life stage in the ocean) in the Bulkley River, British Columbia, Canada, generating a set of best angling practices specifically tailored to that fishery. Similarly, Bower et al. (2018) assessed the effects of C&R on mahseer (*Tor khudree*) in the Cauvery River, India, concluding that survival was high, but more research is needed on larger-bodied individuals that can be most negatively impacted. Another shortcoming of many C&R studies is that the RF stressors are often simulated, whether it's a simulated 'fight' period mimicked by forced exercise or set air exposure treatments that may not necessarily reflect real world angler behaviors. To address this, Roth et al. (2018) examined actual angler behavior *in situ* through a remote observation study in the South Fork Snake River, Idaho, USA, revealing that fish air exposure times were generally lower than those found to cause direct mortality during laboratory studies.

In addition to understanding the physical and physiological effects of C&R stressors on fishes, examining how fish cope with challenges *in situ* is also important. In some cases, when fish are hooked and struggling on the end of the fishing line, they can experience high levels of depredation from opportunistic predators. For example, Mitchell et al. (2018) found there was a major spatial component to depredation rates, which appeared to be driven by fishing pressure and learning by the shark predators. Predation can also be a conservation issue for angled fish post-release. There is growing evidence that fish exposed to greater C&R stressors (e.g., longer air exposure periods) exhibit impaired swimming and cognitive abilities post-release (Brownscombe et al., 2013, 2014b; Cooke et al., 2014), which can lead to increased vulnerability to opportunistic predators (Raby et al., 2014). For example, bonefish can experience post-release predation rates ranging from 0 to 80% depending on predator densities and bonefish condition upon release (Brownscombe et al., 2013; Cooke and Philipp, 2004; Danylchuk et al., 2007; Lennox et al., 2017). In cases where predation rates are extremely high, C&R does not function as a conservation strategy and RF may not be sustainable. Yet, Raby et al. (2018) examined post-release behavior and survival of multiple fish species on the Great Barrier Reef, Australia, and found that C&R stressors caused limited post-release behavioral impairment or predation.

Overall, to achieve sustainable and productive RF it is essential to manage their biological impacts through harvest regulations that maintain sufficient fish stock sizes, population structure, and ecosystem integrity (Arlinghaus et al., 2010; FAO, 2012; Gwinn et al., 2015; Law et al., 2012; Pierce, 2010; Pikitch et al., 2004), as well as implementing fishing practices that enable C&R to function as an effective conservation strategy (Brownscombe et al., 2017). With limited management resources and logistical limitations on regulation complexity it is challenging to regulate fishing effort at the individual fishery level. These challenges can be overcome with knowledge of the conditions (i.e., fishery, fish population, and ecological characteristics) that lead to overexploitation, combined with innovative local management approaches that consider fish population and ecosystem resiliency. C&R is an essential and growing component of RF, and angling practices play a key role in its efficacy. Though there are a generalizable set of recommendations for limiting the impact and maximizing the sustainability of RF, the above examples highlight nuances in the degree of conservation impacts related to interactions between species characteristics, environmental conditions, and angler behavior. Ongoing research is addressing many knowledge gaps by characterizing real-world angler behavior (e.g., Arlinghaus et al., 2017a,b; Klefoth et al., 2011), exploring the impacts of a range of angler behaviors on fisheries that target a range of species in different environments, and examining the consequences *in situ* in habitats with and without opportunistic predators.

7. Transferring best angling practices to anglers

In some cases, conservation-minded angling practices can be implemented through legal frameworks requiring certain gear types or angling techniques by law. For example, the use of circle hooks (opposed to other hook types such as traditional J-shaped hooks) is required by law in many marine fisheries in the United States of America due to their ability to reduce hooking injuries (Sauls and Ayala, 2012; Wilson and Diaz, 2012). This is an example of a straight-forward conservation action, yet, fishing is inherently complex, with diverse environmental conditions, fish characteristics, angler cultures, angler types, and related angling practices (Brownscombe et al., 2017; Cooke and Suski, 2005; Johnston et al., 2010). Hence, developing regulations that cover all fishing situations effectively is challenging, if not impossible. Furthermore, in many cases, fishing regulations are already highly complex, often involving species and location-specific guidelines that result in large, complex documents with which anglers must familiarize themselves to participate legally. Meanwhile, complex regulations have been identified as a barrier for RF participation (Arlinghaus et al., 2008; Cooke et al., 2013; Lester et al., 2003), and non-compliance can be widespread, presenting a considerable threat to fisheries sustainability (Mackay et al., 2018).

Considering the issues with regulatory complexity, in some cases voluntary institutions may be a better approach for aligning angler behaviors and practices with conservation goals (Cooke et al., 2013; Mackay et al., 2018). Yet, translating knowledge to practice, such as having anglers learn and apply these angling practices, can be challenging. Although anglers are often open to engage in conservation action to maintain or improve their fisheries (Granek et al., 2008), education poses a particular challenge due to the complex nature of anglers, especially related to how they receive knowledge on angling practices. In cases where anglers are well organized an local angling clubs, active engagement in joint learning experiments on controversial topics (e.g., whether stocking really delivers benefits to fisheries) has been shown to strongly outperform passive forms of education in Germany (Fujitani et al., 2016). In Pacific salmon fisheries, Nguyen et al. (2012) identified diverse types of anglers that prefer particular information sources, such as in person interactions, pamphlets, and the internet, suggesting that a range of education means is likely to more broadly reach the angler population. Similar to Fujitani et al. (2017), Mannheim et al. (2018) achieved success in promoting conservation-minded angling practices in a South African shore-based recreational fishing league by first integrating scientists into the fishing community to build trust, then implementing multiple behavioral interventions, including rule changes, improving angler knowledge, behavioral modelling, rewards, penalties and feedback. Mannheim et al. (2018) provide an example of overcoming angler distrust of scientists and management (Dedual et al., 2013) to identify effective approaches to influencing angler behaviors such as rewards and penalties.

In the above case (Mannheim et al., 2018), working with a competitive league affords certain opportunities to implement local-scale organizational rules to influence angler behavior. However, in many cases, anglers are less organized and more difficult to reach. Another highly effective approach to influencing angler behavior is through behavioral cues from their community, or social norms (Bova et al., 2017). Further, many anglers are becoming easier to reach across the world due to the growth of social media and fishing communities on the internet. This has enabled recent conservation-focused social media movements, one of the most prominent of which is Keepemwet (https://www.keepemwet.org). Danylchuk et al. (2018) describe the movement and reflect upon its success, crediting its simple core message, to keep captured fish in the water to reduce or avoid air exposure (regarded as one of the largest contributors to fish stress and mortality during angling; Cook et al., 2015), which is reflected in pictures of captured fish shared in online fishing communities. The movement has a broader set of goals and recommendations aimed at promoting conservation-minded angling practices, which are promoted through a dedicated website and social media accounts.

8. Conclusions

Recreational fisheries are complex social-ecological systems that involve the exploitation and management of natural resources and provide significant social, educational, economic and conservation benefits to human societies around the world. As the nature of recreational fisheries is diverse and rapidly changing in some areas of the world, so are our approaches to scientific research, monitoring, and management. Here, we covered the ongoing research presented in this special issue on recreational fisheries and elsewhere in the context of key contemporary literature on the topic appearing in other outlets. As new RF are developing and growing (particularly in economies in transition) and others shrinking in popularity (some in highly urbanized societies), appropriate management strategies are necessary to deal with these changes. Furthermore, Kristianson, (2018) reminds us that regardless of the quality of scientific information and management framework, these are always imbedded in the context of political and governance systems (international, national or local) that are neither static nor predictable and ultimately determine how fisheries are managed (Arlinghaus et al., 2017a,b; Carpenter et al., 2017).

The characterization of participation and understanding the factors driving participation is essential to maintain resilient RF and social and economic value they generate, while knowledge of their value plays a key role in effective resource allocation and government policy. Fish stocking is playing a prominent role in supporting RF, and ongoing research is addressing issues surrounding its potential biological impacts, and also optimizing stocking approaches to maximize angler satisfaction and participation. As human populations continue to grow, anglers are catching increasing numbers of fish. Managing fishing effort is therefore essential to avoid overexploitation, but poses major challenges that can be overcome by understanding the social, spatial, and biological characteristics of fisheries and employing innovative management approaches. C&R is an essential and growing component of sustainable fisheries; however, it is only effective when its impacts on fish survival and fitness are minimal. Much ongoing research is addressing how angling practices can be molded to minimize the negative impacts of C&R. Further, this growing body of best angling practices must be disseminated to anglers effectively through new avenues, such as social media, to accomplish these conservation goals. The increasing impacts that growing human populations are having on the environment are threatening many of the natural resources and ecosystem services they provide, including valuable recreational fisheries. However, with careful development of research initiatives, monitoring and management, we can ensure recreational fisheries are sustainable and generate positive outcomes for both society and natural ecosystems. To accomplish this, there is a growing need to treat RF as complex social-ecological adaptive systems, with feedbacks across subsystems that lead to varied outcomes across multiple spatial scales (Arlinghaus et al., 2017a,b).

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