Advancing an integrated protocol for rapid assessment of catch-and-release recreational fisheries in the developing world

by

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Dedication

I dedicate this work to the hidden gods of India, who shine in every run and riffle on the river; to the mahseer, who shared their secrets; and to F., J. and H., who left too soon but shared and inspired so much. Special thanks and boundless gratitude to E., for walking with me, and to B. and F., for believing always.

Abstract

The global recreational fishing sector is the dominant fishing sector in freshwaters of the highly developed world and often more economically powerful than commercial fisheries, yet it is also ignored in international policy and suffers widespread data deficiencies from a lack of research. Despite the magnitude of potential benefits and consequences, little is known about recreational fishing activity, particularly in developing countries. I propose using an integrated rapid assessment protocol that adopts a social-ecological systems (SES) approach to address data deficiencies in catch and release (C&R) recreational fisheries of the developing world. In this work, I use the mahseer (Tor spp.) C&R recreational fishery of the Cauvery River, India as a case study. This dissertation identifies which linkages in the SES are most likely to influence sustainable management of the mahseer recreational fishery. To identify the nature and scope of the knowledge gaps in recreational fisheries of the developing world, I conducted a survey of fisheries professionals to rank knowledge and management needs. The results of the survey confirmed that recreational fisheries are subject to severe data deficiencies that require local level assessment to resolve. I then worked with local stakeholders to prioritize a research agenda that identified the need to research physiological responses of mahseer to C&R and angler behaviours and perspectives as valuable to this fishery. Therefore, I examined the physiological responses of mahseer to C&R, measured mahseer post-release movements, and compared the responses of mahseer caught multiple times through simulated capture processes. Finally, I conducted angler surveys to identify angler behaviours, perspectives, and information sources, then used expert interviews to place this information in local context. Overall, results show that mahseer are robust to C&R, but larger mahseer are likely to experience negative consequences post-release, and effects of combined stressors may be cumulatively interacting. There are opportunities to improve relationships among management organizations, angling groups and local communities to improve information flow and benefit-sharing throughout the mahseer fishery. The integrated rapid assessment protocol provides essential baseline data on biological and social responses to recreational fishing activity, and acts as a roadmap to guide future research and management efforts.

Keywords: conservation social science, data deficiencies, fish conservation, freshwater fisheries, India, mahseer, social-ecological systems

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Thesis Format and Co-authorship

This dissertation consists of eight full chapters, including six data chapters in manuscript format. Two are currently published in peer-reviewed journals, two are currently under review in peer-reviewed journals, and the two remaining data chapters are currently being prepared for submission to peer-reviewed journals. As such, there is some repetition throughout the various chapters (particularly in the introductions to each chapter). All chapters in this dissertation reflect my research, however, many co-authors contributed to each study. Below, I list my contributions, and those of my co-authors, to each chapter.

Chapter 2. Knowledge gaps and management priorities for recreational fisheries in the developing world

Bower, S.D., Aas, O., Arlinghaus, R., Beard, T.D. Jr., Cowx, I.G., Danylchuk, A., Friere, K., Potts, W., Sutton, S., and Cooke, S.J. In Review. Knowledge gaps and management priorities for recreational fisheries in the developing world. Fish and Fisheries

I designed the study, collected and analyzed the data, and wrote the manuscript. All co-authors contributed to manuscript editing. Cooke, Aas, Arlinghaus, Potts, Friere, and Sutton additionally contributed to survey design. Cowx and Beard contributed to identifying potential respondents.

Chapter 3. Involving recreational fisheries stakeholders in development of research and conservation priorities for mahseer (*Tor* spp.) of India through collaborative workshops

Bower, S.D., Danylchuk, A.J., Raghavan, R., Clark-Danylchuk, S., Pinder, A., Alter, A., and S.J. Cooke. 2017. Involving stakeholders in development of research and conservation priorities for mahseer (*Tor* spp.) of India using hands-on research participation and workshops. Fisheries Research. 186(3):665-671.

I designed the study, collected and analyzed the data, and wrote the manuscript. All co-authors contributed to manuscript editing. Danylchuk and Cooke additionally contributed to study design. All authors participated in conducting workshops and Raghavan, Pinder, and Alter were integral to organizing workshops.

Chapter 4. Rapid assessment of the physiological impacts caused by catch-and-release angling on blue-finned mahseer (*Tor* sp.) of the Cauvery River, India

Bower, S.D., A.J. Danylchuk, R. Raghavan, S. Clark-Danylchuk, A. Pinder and S.J. Cooke. 2016. Rapid assessment of the physiological impacts caused by catch-and-release angling on blue-finned mahseer (*Tor* sp.) of the Cauvery River, India. Fisheries Management and Ecology. 23: 208-217.

I designed the study, collected and analyzed the data, and wrote the manuscript. All co-authors contributed to manuscript editing. Danylchuk and Cooke additionally contributed to study design. All authors participated in field work.

Chapter 5. Identifying sub-lethal behavioural responses of *Tor khudree* to catch-and-release recreational angling using radio telemetry

Bower, S.D., Mahesh, N., Raghavan, R., Danylchuk, A.J., and Cooke, S.J. (In Review). Sub-lethal responses of mahseer (*Tor khudree*) to catch-and-release recreational fishing. Fisheries Research, WRFC8 Special Issue.

I designed the study, collected and analyzed the data, and wrote the manuscript. All co-authors contributed to manuscript editing. Danylchuk and Cooke additionally contributed to study design. Mahesh participated in field work and was integral to organizing logistics.

Chapter 6. Consequences of simulated multiple catch and release events on reflex impairment, ventilation rate, and body condition in *Tor khudree*

Bower, S.D., Raghavan, R., Danylchuk, A.J., Szekeres, P., and Cooke, S.J. (In Prep). Consequences of simulated multiple catch and release events to whole body impairment and body condition in *Tor khudree*.

I designed the study, collected and analyzed the data, and wrote the manuscript. All co-authors contributed to manuscript editing. Cooke additionally contributed to study design. Szekeres participated in field work.

Chapter 7. Angler perceptions and expert knowledge of the Cauvery River mahseer (*Tor khudree*) catch-and-release recreational fishery in Karnataka, India

Bower, S.D., Raghavan, R., Danylchuk, A.J., Potts, W.N., Sutton, S., and Cooke, S.J. (In Prep). Angler perceptions and expert knowledge of the Cauvery River mahseer (*Tor khudree*) catch-and-release recreational fishery: the benefit of social science perspectives.

I designed the study, collected and analyzed the data, and wrote the manuscript. All co-authors contributed to manuscript editing. Danylchuk, Sutton, Potts, and Cooke additionally contributed to study, survey, and interview design

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Chapter 1. General Introduction

The Importance of Recreational Fisheries

Recreational fishing, defined as the capture of fish for purposes other than primary consumption or commercial sale at official or unofficial market (FAO 2012), is a highly varied activity characterized by numerous gears, methods, and objectives. Recreational fishing activity has been taking place for thousands of years, first described in Egyptian pictorial images (Arlinghaus et al. 2007). Management of recreational fishing activity in the form of rules governing angling behaviour has been occurring in Europe since the Middle Ages (Policansky 2002). Yet, the recreational fishing sector is often incorrectly viewed as unimportant.

Despite large expenditure contributions to the global economy (more than 19 B USD/year, World Bank 2012) and the lobby power wielded by the recreational fishing sector in some countries (e.g., between Florida commercial and recreational fishers, Smith and Jepsom 1993; in Australia, McPhee et al. 2002), recreational fisheries remain under-studied and under-reported at the international level (FAO 2012). Coarse estimates have suggested that over 30 billion fish are captured (and harvested or released) annually (Cooke and Cowx 2004), and in some countries, harvest from recreational fisheries exceeds that of commercial fisheries (e.g., in inshore areas of Australia, McPhee et al. 2002). Indeed, recreational fishing is currently recognized as the dominant use of fish stocks in many freshwater habitats of industrialized nations (Arlinghaus et al. 2002) and is currently on the rise in the developing world (Cowx 2002). Yet, the clear majority of research involving recreational fishing, species' responses to recreational fishing practices, and recreational fishing policy and management focuses on a very small number of countries and a very small number of species (e.g., in catch and release [C&R]

research, Cooke and Suski 2005). This inattention has the potential to underestimate negative effects on fish populations and even fishing communities through recreational fishing pressure (e.g., see McPhee et al. 2002), but also fails to promote understanding of the ways recreational fishing can act as an important contributor to human well being, as a conservation tool, and as a source of income and livelihood for fishing communities (Tufts et al. 2015; Barnett et al. 2016).

The Global Significance of Recreational Fisheries

In highly developed countries, recreational fishery development occurred as economic prosperity increased and reliance on fishing as a source of protein and economic profit decreased (Arlinghaus et al, 2002; Beard et al, 2011). In low to medium development countries, however, small-scale commercial and subsistence fishing activities continue to provide the dominant source of income (FAO, 2010) and protein (Hall et al, 2013) for millions of people, yet recreational fishing activity is believed to be on the rise in these countries too (Cowx 2002). This crucial difference in both degree of economic development and degree of industrialization indicate that patterns of recreational fishery activity and growth that apply to the highly industrialized world are unlikely to be suitably applied as models for recreational fisheries in the developing world. For instance, sustainability issues in recreational fisheries such as targeting threatened species (e.g., Cooke et al. 2016; Shiffman et al. 2017) and introduction of invasive species (Alexiades et al. 2017) are relevant to recreational fisheries globally, but recreational fisheries in the developing world may be further constrained by issues such as resource conflict among small-scale fisheries sectors, and decreased resilience to any economic or ecological shocks (FAO 2010). It is important to note that these same concerns can also apply to recreational fisheries in highly industrialized countries. For example, conflict between recreational fishers and indigenous fishers over access and fishing rights occur in Canada

(Nguyen et al. 2016; in coastal communities in Australia, Voyer et al. 2017). However, the consequences arising from these concerns are arguably higher in the developing world, where fewer social safety nets exist to protect fishing communities from realization of risks associated with recreational fishing.

The continued development of the global recreational fisheries sector is expected to have ecological, social, and economic implications for many countries. These consequences may include ecologically based alterations to the aquatic system, such as recreational fishing contributions to overfishing (Post et al. 2002; Post et al. 2013) and anthropogenic genetic selectivity or behavioural changes (e.g., selection for shy individuals by harvesting bold individuals, Arlinghaus et al. 2017). Potential social implications of recreational fishery development include alterations of social parameters of the fishery, such as changes in governance structure (e.g., development of recreational fisheries in Brazil has led to decreased access rights for commercial fishers, Friere et al. 2012) and increased social conflict (see Bower et al. 2014).

In contrast to these risks, recreational fisheries in the developing world have been explored as an alternative livelihood strategy through ecotourism to generate revenue (e.g., Wood et al. 2003) and as an economic incentive to protect fish species and habitat by earning potential revenue from non-destructive activities (e.g., catch and release angling tourism in Mongolia, Jensen et al. 2009; and in India, Everard and Kataria 2011). However, growth of the recreational fishery sector in these regions can also result in heightened social conflict as larger numbers of individuals compete for access to the resource (Bower et al. 2014; Øian et al. 2017). Also, tourism-based recreational fisheries may foster conflict with resident fishers as a result of foreign culture and differences (Bower et al. 2014). For example, voluntary C&R could cause conflict or animosity due to different views about this concept as some may view it as unethical (Arlinghaus et al. 2007). The sustainable maturation of the global recreational fishery sector will therefore depend on developing a new framework through which to view the activity, one in which the challenges and benefits distinct to recreational fishery growth in the developing world are identified and addressed.

Catch and Release Recreational Angling

The term 'catch and release' refers to the practice of returning fish to the water after an angling experience, and is commonly used on a voluntary or mandated basis as a management tool for promoting sustainable recreational fisheries (Arlinghaus et al. 2007). The practice can be diverse in its execution, ranging from landing a fish after a short angling period and immediately returning it to the water with little to no air exposure, to that in which a fish experiences exhaustion after a lengthy angling event, is air exposed for several minutes (for photo opportunities, for e.g.) and subsequently kept in a live well and returned to the water in a different location (Arlinghaus et al. 2007). Numerous social and biological factors influence the time taken for an angled fish to recover, or not recover, from an angling event. Angler experience, gear types, and angling behaviours (i.e., length of angling event, prolonged air exposure) have been shown to impact response severity and recovery times or mortality, as have numerous physical and biological variables, including water velocity, water temperature and body size of fish (see Muoneke and Childress 1994; Bartholomew and Bohnsack 2005; Arlinghaus et al. 2007; Cooke et al. 2013; Cook et al. 2015).

The immediate response to C&R events in fishes is similar to that seen in burst exercise (Donaldson et al. 2013): energetic limitations for aerobic respiration are exceeded and the shift to anaerobic respiration leads to increases in lactate production, while secretion of stress hormones leads to production of glucose (Wood 1991). In addition, exhaustive stress leads to a decrease in pH of the blood as a result of metabolic (via the production of lactate and use of stored ATP) and respiratory (via oxygen depletion) acidosis (Wood 1991; reviewed in Cook et al. 2015). Measurements of these responses can serve as powerful indicators of species-typical responses to C&R events (Skomal 2007). Measurement of blood parameters such as blood glucose and lactate levels are also simple to carry out in the field using point-of-care devices (validated in Stoot et al. 2014), with results being obtained immediately. Similarly, whole body measurements of stress response, such as reflex impairment indicators (Davis 2010) are simple to use, non-invasive, and require no additional equipment.

Post-release mortality of fish after a C&R angling event, due to species-specific physiological or behavioural characteristics, is another consideration for the evaluation of the practice, such that adopting C&R as a conservation practice may not be sufficient to maintain healthy sport fish populations in some species if post-release mortality rates are high (Cooke and Suski 2005; Cooke and Schramm 2007). Like recreational fisheries research more generally, the majority of the C&R research has involved economically important gamefish in the developed world (e.g., *Salmo salar*, *Micropterus salmoides*, *Sander vitreus*) with little work being done on species that occur in the developing world.

Sub-lethal effects of C&R such as alterations to feeding and reproductive behaviours, long-term physiological changes, and increased susceptibility to disease and parasite-loading may also be realized on a species-specific basis (Cooke et al. 2013). Studies of individual fish behaviour post-release suggest that altered levels of mobility may indicate compromised fitness resulting from C&R angling, such as through an inability or disinclination to migrate, a lengthened migration period (via slowed speeds or 'fall back', a term given to fish who travel backwards with the flow of water after an angling event), or increased local movements, as seen in studies of Atlantic salmon (*S. salar*) in Norway (Thorstad et al. 2003 and Thorstad et al. 2007, respectively). Other sub-lethal effects associated with C&R include decreases in parental care or nest abandonment (e.g., in *Micropterus dolomieu*, Suski et al. 2003) and decreased response to predator stimuli (e.g., in *Lutjanus carponotatus*, Cooke et al, 2013b). Exacerbated response and recovery patterns may have detrimental impacts on both individual fish and potentially at the population level. For example, prolonged recovery from angling induced stressors has been shown to increase the likelihood of post-release predation in prey species such as Bonefish (*Albula vulpes*), which are commonly targeted by small sharks shortly after release (Danylchuk et al. 2007). Currently, linkages to infer population-level effects from individual survivorship without extrapolation are lacking (Skomal 2007; Arlinghaus et al. 2007; Cooke et al. 2013) however, such linkages may become easier to establish when more short-term physiological studies are paired with longer-term behavioural assessments. Identification of the stressors associated with C&R, and understanding the way they interact and their role in fish recovery should be considered essential components of C&R research.

The effectiveness and suitability of C&R practices as a conservation tool does not depend solely on the response of the target species to the activity, but also relies heavily on the willingness of the angler to participate in the behaviour (Sutton and Ditton, 2001). As with most aspects of the recreational fishing sector, the modes of behaviour and motivations of recreational anglers are diverse and complex (Arlinghaus et al. 2007) and will have a significant role to play in maintaining the sustainability of the sector as it develops. There are also cultural concerns surrounding C&R practices, as the concept of angling for pleasure but not retaining captured fish for consumption is not a universally accepted ethos (Arlinghaus et al. 2007). Indeed, C&R is banned in some countries, such as Germany (Arlingahus 2007). As such, the option of promoting C&R as a method for achieving sustainability in recreational fisheries should be evaluated on a case-by-case basis, and include considerations of species-specific responses, understanding of angler behaviours, and degree of social acceptability.

Recreational Fisheries as a Social-Ecological System (SES)

Sustainable management of existing and developing recreational fisheries will not rely solely on research related to species-specific responses to fishing pressures or human dimensions of angling, but will require recognition of the fishery as a coupled social-ecological system (SES; Hunt et al. 2013; Arlinghaus et al. 2016, Arlinghaus et al. 2017; Figure 1.1). An SES is a closed ecological system that is closely linked and interacts with one or more social systems (Anderies et al. 2004). In a fisheries SES, key system components are identified and placed in nested systems (as in Ostrom 2007; see also Berkes and Folke 1998). For example, the recreational fishery SES is nested within the broader fishery SES, which in turn is nested in the broader aquatic resource SES (which includes other resource users or purposes such as water extraction for agricultural uses; Hunt et al. 2013). These system components are then described in terms of relationships and interactions such that the components affecting key processes (referred to herein as ‘drivers’) and important relationships among system components (referred to herein as ‘linkages’) are identified (Ostrom 2007). Further, the dynamic and stochastic nature of both social and ecological systems combine to identify the fishery SES as a ‘wicked problem’, or a situation in which problems are inherently difficult to solve due to a combination of their complexity and changeability over time (Rittel and Webber 1973; Jentoft and Chuenpagdee 2009). Thus, recognition that social factors are fundamentally connected to both the ecological and economic aspects of fisheries systems in research and decision-making processes is required to optimize fisheries outcomes (Aas 2002).

Integrated studies that consider both biological and human systems can identify new or complex issues in a system that may not be possible through natural or social science study alone (Berkes et al. 2016). Indeed, Arlinghaus et al. (2016) note that while many studies have called for increased recognition of the role human dimensions play in fisheries management, further integration of ecological and social systems (for example, using SES approaches) is required to better understand the influences of linkages between these systems. It is these characteristics that lend support to including an integrated perspective in recreational fisheries research that not only recognizes the importance of key biological and human dimensions components, but actively seeks to understand the way these components interact.

Recreational fisheries research that incorporate SES approaches should optimally focus on the regional or local level. The diversity of attributes of individual fisheries is such that tools and strategies for sustainable management must be developed at a regional or local scale, as it is local responses to large-scale drivers and local conditions that will determine both the characteristics and impacts of the recreational fishery (Arlinghaus and Cowx 2008). Moreover, the response of local community members and stakeholders to recreational fishery development will dictate, to a large degree, the success of the sector overall within the local community (see Jentoft et al. 2012, for examples of stakeholder influence on the success of marine protected areas; Danylchuk and Cooke 2011 for discussion of angler response to aquatic protected areas). While there is a need for a suite of tools to facilitate the assessment of small-scale fisheries in developing countries that will enhance the capability of local communities in the development of management and governance structures (Prince 2010), little research to date has managed to accomplish this task using an integrated approach that incorporates ecological, social and economic considerations. To be of use to managers, such approaches must also offer transferable insights (i.e., allow for local scale study that can inform broad scale analysis) for a variety of applications that can be applied effectively in different situations and contain avenues for including the socio-economic context of the fishery community.

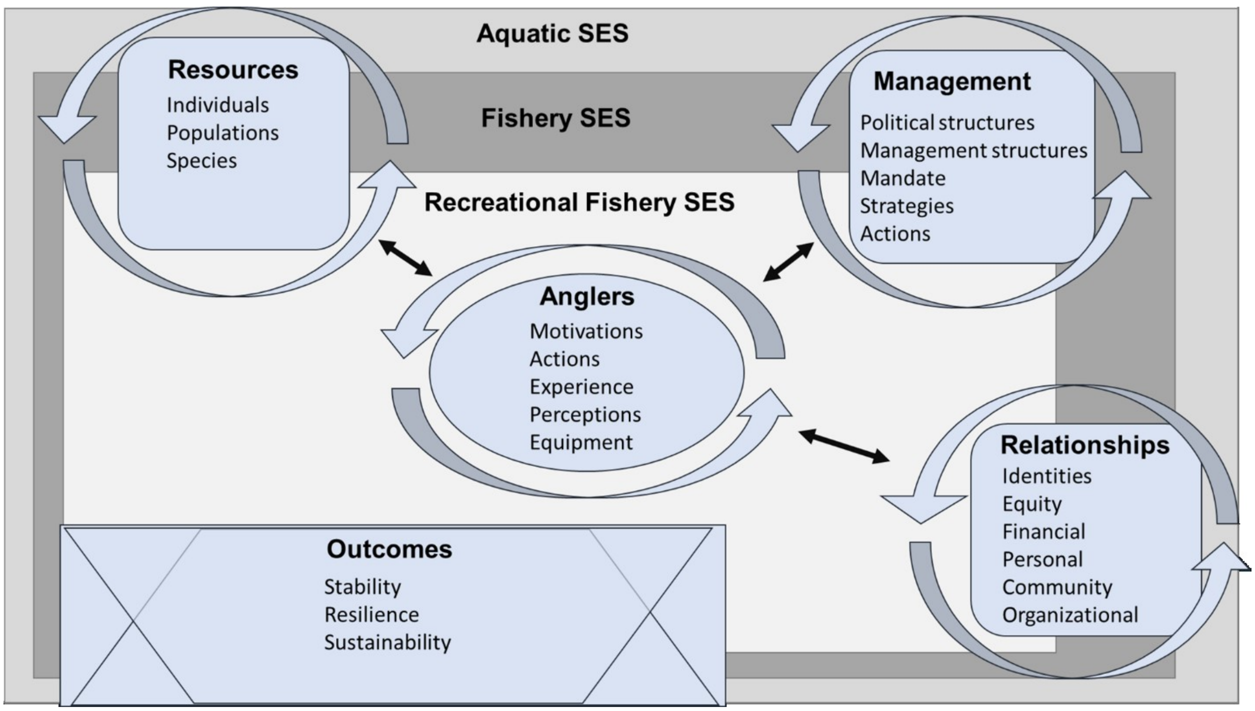

Figure 1.1 A depiction of a recreational fishery SES as adapted from Hunt et al. (2013), with added consideration of the role that relationships play in influencing outcomes, and the embedded nature of the recreational fishery SES in surrounding SES (as in Ostrom 2007). The recreational fishery social ecological system (SES) is nested in the broader fishery sector SES, which includes other harvested fish species and small-scale commercial, subsistence, and indigenous fishing activities. The fishery SES is nested in the broader aquatic ecosystem SES, which includes all other aquatic ecosystem components and other aquatic resource users, such as the agricultural and tourism industries. Embedded shapes (Resource, Management, Relationships) indicate key subcomponents of the recreational fisheries SES that link it via potential routes of action to both nested SES. Note also that the management subsystem can refer to both informal and formal management systems. The circular angler subsystem depicts the potential routes of action that influence each subsystem, while the arrows connecting the angler system to each subsystem illustrate the nature and direction of linkages among all three SES

systems, i.e., show potential routes of effect. It is these arrows that represent the focus of this research. Cyclical arrows around the angler system and related subsystems indicate the ability of all potential interactions to influence and interact with each other, e.g., angler actions that influence the resource system via introduction of invasive species potentially influence fish populations and species, the decline of which can influence the proliferation of invasive species. Though not pictured (for clarity), potential routes of effect also occur among the nested subsystems and fishery and aquatic SES components (e.g., there are linkages between the management and resource subsystems in the broader fishery SES). All of the potential routes of action can result in outcomes (pictured at bottom left). The trapezoid at the fore illustrates processes wherein recreational fishery SES actions result in minimal transference of outcomes to the fishery SES and aquatic SES. The inverted trapezoid (partly pictured behind the first) represents wherein recreational fishery SES actions result in major transference of outcomes to the fishery and aquatic SES. The square shape at the back represents processes wherein actions in the recreational fishery SES result in moderate transference of outcomes to the fishery SES and aquatic SES.

Recreational Fishery Assessments and Challenges Specific to Assessments in the Developing World

Stock assessment in fisheries can increase the successful prediction of responses of fish populations to fisheries activities and provide fisheries managers with an evidence-base to support decision-making processes (Lorenzen et al. 2016). Traditional forms of fisheries stock assessment are most commonly applied in marine fisheries and involve developing mathematical models of fishery data for harvest protocols, represented by such measurements as maximum sustainable yield (MSY; Larkin 1977), and expected maximum sustainable yield (E_{msy}; Hilborn 2007). However, assessment does not have to be based on traditional goals of stock assessment (e.g., MSY, Walters and Martell 2002; can prioritize management objectives over stock assessment, Mahon 2006), and while data collection is a particular challenge for small-scale fisheries (Andrew et al. 2007), assessments can be accomplished even in data-poor situations (Lorenzen et al. 2016). For example, observational studies can be combined with simple indicators and are flexible so as to be applicable in many situations and to answer many different research questions (Lorenzen et al. 2016). Data for such assessments can be gathered from surveys, logbooks, and direct sampling (e.g., eDNA, mark-recapture, Cooke et al. 2016). Additionally, patchy data can be supplemented with concentrated efforts in data collection using citizen science or collecting local and traditional ecological knowledge (Cooke et al. 2016; see review on techniques using ethnobiology to extract fisheries information, Morales et al. 2017).

The need for improved assessment in global fisheries (Beard et al. 2011; Cooke et al. 2016; Lorenzen et al. 2016), and recreational fisheries specifically (e.g., Arlinghaus et al. 2016) has been widely recognized. Inland fisheries in particular are commonly managed without formal assessment (Lorenzen et al. 2016). Indeed, improved estimation, and standardized methods of assessment were identified as key recommendations of the global conference on inland fisheries at FAO in Rome (January 2015), along with the need to expand the range of assessment approaches used (Cooke et al. 2016).

Progress in improving assessment is particularly relevant to recreational fisheries in the developing world. Formal management of recreational fisheries is not known to occur in many developing countries and while informal and traditional forms of management likely do occur in many countries (e.g., as voluntary institutions, Cooke et al. 2013), they are not always sufficient to account for increasingly globalized pressures on fish populations (e.g., Maggs et al. 2015). Yet, the majority of recreational fishery management occurring in the developing world does so with little to no evidentiary basis or monitoring, a situation that is precarious (Arlinghaus et al. 2016). Thus, in addition to the data-poor assessment techniques that are available, novel assessment processes for data-poor recreational fisheries are needed (Beard et al. 2011; Arlinghaus et al. 2016).

Some research initiatives are underway that can be helpful in meeting the need for improved data-gathering for data-poor recreational fisheries in the developing world. Fishery performance indicators as designed by Anderson et al. (2015) to assess the biological, social, and economic performance of commercial fisheries can be translated such that they are applicable to recreational fisheries also. Studies of the Niugini black bass (*Lutjanus goldiei*) recreational fishery of New Guineau have combined human dimensions and biological study in a preliminary analysis to identify key areas of sustainability research (Sheaves et al. 2016) and suggested multidisciplinary practices to promote sustainable growth of recreational fishing ecotourism projects (Barnett et al. 2016). Rapid assessments, in this context defined as a brief field study designed to maximize the amount of information (e.g., behavioural, physiological characteristics or responses) gathered in a short period of time, are also gaining recognition as an assessment tool for developing world fisheries. While traditional forms of assessment often occur over long time or spatial scales (e.g., for decades), a rapid assessment can be considered relatively brief if it occurs over a period of a single year. Popular C&R species such as peacock bass (*Cichla ocellaris*, Bower et al. 2016), and common snook (*Centropomus parallelus*, Lennox et al. 2015) have been studied from a rapid assessment perspective to quantify injury and mortality, and to identify physiological responses to the process of C&R. Ideally, each recreationally fished species should be researched thoroughly, and the results of this research incorporated into adaptive management (or similar) frameworks. However, budgetary resources are limited, and timeliness is essential, thus rapid assessments may serve as a tool for triage, identifying areas in need of further research and immediate study.

Case Study: The Mahseer C&R Recreational Fishery

The mahseer (*Tor* spp.) C&R recreational fishery of the Cauvery River, Karnataka, India, is an ideal example of a data-deficient recreational fishery that would benefit from an integrated rapid assessment process. Recreational fishing has been taking place on the Cauvery since British occupation (~1873, Gupta et al. 2015), but increased in popularity after the 1940s when anglers began targeting a large-bodied group of cyprinids known as mahseer (*Tor* spp.; Sehgal 1999). Mahseer occur throughout Asia and eight species have been formally identified in Indian waters, though clarification of taxonomic relationships is ongoing, and it is likely that formal identification of additional mahseer species will occur. *Tor khudree*, otherwise known as the blue-finned mahseer, was first identified in the Mula Mutha River near Pune, Maharashtra (Sykes 1839) and is believed to occur in several river systems in South India (Raghavan 2011) but it is currently unclear whether native populations occurred in the Cauvery River. *T. khudree* is believed to be experiencing widespread population collapse in its range and so is listed on the IUCN Red List as 'Endangered' (Raghavan et al. 2011). The humpback mahseer (not yet formally described), a native species to the Cauvery River, has also undergone dramatic population decline (Pinder et al. 2015). It is widely accepted that stocking of hatchery-bred *T. khudree* in the Cauvery may have played a role, among other factors, in the decline of this native species (Pinder et al. 2013; Pinder et al. 2015). Despite the lengthy history of recreational fishing of mahseer in India, no studies had ever been conducted examining *T. khudree* responses to C&R practices, nor had *T. khudree* ever been studied in the Cauvery River.

The Karnataka Fishery Department (KFD) mandate is heavily focused on supporting small-scale and subsistence fishers through stocking (Bower et al. 2016). As such, it is possible for organizations to apply to the KFD to initiate recreational fisheries management in stretches of river through a leasing system (Pinder and Raghavan 2013). During the 1970s, anglers and conservationists who had noted declines in the catch rate and average size of mahseer in the Cauvery formed conservation organizations to address the issue (Pinder and Raghavan 2013), encouraged by the National Commission on Agriculture (Sehgal 1999). These anglers and conservationists formed two distinct groups; the Coorg Wildlife Society (CWS) near the headwaters of the Cauvery River in Coorg, and the Wildlife Association of South India (WASI) based in Bangalore. Both organizations began managing stretches of the Cauvery River for recreational fishing activities and instituted C&R only policies for mahseer. In 2009, after a legal dispute between business owners resulted in a Supreme Court of India challenge, changes were made to the Wildlife Protection Act of India (1972) that equated C&R angling to baited hunting activities (Gupta et al. 2015). This decision resulted in the closure of any C&R activities located inside protected lands, which fall under the jurisdiction of the Forest Department (Karnataka). The change was enforced slowly, but by 2012, the only mahseer C&R angling locations remaining on the Cauvery that were not banned by the legal action occurred in two areas: WASI Lake and Forbes Sagar (controlled by WASI), and a 35-km leased stretch in Coorg (controlled by CWS). Angling is also permitted at a third location on KRS Dam, however, stocked common carp (*Cyprinius carpio*), catla (*Catla catla*), and rohu (*Labeo rohita*) are the most common target species there as mahseer catches have become relatively rare.

As *de facto* management bodies for mahseer recreational fishing, both CWS and WASI have adopted different management approaches. Both organizations require memberships and or licenses to fish, and provide anglers with rules to follow, and both organizations require C&R for mahseer species. In CWS territory, memberships are currently limited to individuals from the Coorg district, and there is a rod limit for the managed stretch of 8 rods per day (Aiyappa C.P., personal communication). It is noteworthy that though the length of the CWS stretch is recognized as being 35 km, CWS is unable to manage the entirety of the stretch with the resources available and so focuses their efforts on a smaller stretch (approximately 8 km), which includes a protected area (sanctuary) where no fishing of any kind is permitted. In WASI Lakes, anglers are additionally encouraged to harvest invasive species (*Tilapia* spp., *Clarias gariepinus*).

Overall Research Objective and Research Steps

Creating a comprehensive picture of recreational fisheries in the developing world will help us to understand and potentially predict challenges or areas of concern related the sustainable management of target species, including migratory and endangered species. The implementation of an integrated component in this research, particularly when viewed through a SES lens, will allow for increased predictive power regarding angler behaviours and attitudes, enhancing the effectiveness of management strategies. Thus, the objective of my PhD research was to use the case study of the mahseer C&R recreational fishery to develop an integrated rapid assessment protocol designed to identify species-specific responses to recreational fishing activity and common angler behaviours and perspectives, and to place these findings in a relevant, local-scale context. This objective can be framed as an overarching research question: Which linkages in the recreational fishery SES are most likely to influence sustainable growth and management of the Cauvery River mahseer recreational fishery? The overall research objective is highly exploratory, but while I addressed this question using SES-oriented approaches that combine biological and sociological methodologies, each portion of the rapid assessment is based on testable hypotheses and predictions.

To begin, I explore the nature of data deficiencies in the recreational fisheries of the developing world by identifying and prioritizing knowledge gaps and management needs in the sector (Chapter 2). In this chapter, I compiled responses from recreational fisheries professionals in 39 respondent countries and categorized knowledge gaps and management needs according to consensus priority and theme. I then used these themes to offer recommendations on next steps to address data deficiencies in global recreational fisheries.

Chapter 3 represents the first step of the integrated rapid assessment protocol, wherein I applied participatory approaches by conducting stakeholder workshops to work with local experts in devising a list of research priorities to support mahseer conservation. This process represents the exploration of local phenomena relevant to the mahseer C&R recreational fishery and the outcomes formed the basis of the hypotheses tested during the remainder of the rapid assessment.

Thus, in Chapters 4 – 6, I set out to test the following hypotheses using rapid assessment methodologies:

- 1- That the duration of angling, handling, and air exposure times would influence impairment in mahseer;
- 2- That angling, handling, and air exposure times would influence the post-release behaviour of mahseer;
- And, 3- that the number of capture events would influence post-release impairment in mahseer.

In these chapters, I used validated methods applied over short timeframes to evaluate not only the physiological and behaviour responses of mahseer to common C&R practices, but to explore the rapid assessment process strengths and weaknesses.

In Chapter 7, I studied the mahseer C&R recreational fishery from a sociological perspective, to identify how anglers receive information on angling practices, which practices they use, and their perspectives on conservation. Using the data from an online angler survey designed to gather this information, I was also able to test the hypotheses that angler years of experience and reported expertise would influence angler behaviour. Additionally, I used interviews of mahseer recreational fishing experts to discuss issues and topics pertinent to the fishery such that I could place the findings of both the biological and sociological study into a locally relevant context.

In my general discussion (Chapter 8), I address my overarching research question using the findings from the integrated rapid assessment by synthesizing the findings of the preliminary exploration chapters (Chapters 2, 3) and all four rapid assessment chapters (Chapters 4 – 7). I examine these findings using a SES approach such that priority linkages that can support or constrain sustainability in the mahseer C&R recreational fishery of the Cauvery River are identified. Additionally, I offer recommendations and caveats for rapid assessment processes and research examining developing world recreational fisheries. I use these findings to develop comprehensive suggestions that can be implemented to enhance sustainable growth and management of recreational fisheries.

Chapter 2. Knowledge gaps and management priorities for recreational fisheries in the developing world

Abstract

Millions of individuals worldwide rely on recreational fishing activities for leisure, personal consumption, and employment. Recreational fishing has become the dominant fishery in the freshwaters of much of the highly developed world. In developing countries, recreational fisheries occur within a different set of contextual conditions than in highly developed societies. To date, little is known about attributes of the recreational fishing sector in developing countries. I conducted a survey of fisheries personnel designed to identify knowledge gaps surrounding recreational fishery development, in addition to gathering information about specific fishery attributes in developing countries. Recreational fishing was socially important (but less so than small-scale commercial and subsistence fisheries) and is expected to grow in most countries that were surveyed, but more so in respondent countries with higher Human Development Index rank. Recreational fisheries were described as mainly consumption oriented. Non-resident tourists most often used marine waters and resident recreational fishers most often used fresh waters. There was strong agreement among respondents about the need to address data deficiencies and evidence of the need to adopt a social-ecological systems approach when researching and managing recreational fisheries. The knowledge gaps and management needs identified provide a template for international bodies and recreational fishing organizations (such as the regional fisheries bodies of the Food and Agricultural Organization of the United Nations, and local and international fishing associations) to help advance the sustainable development and management of the global recreational fisheries sector in cooperation with other fisheries sectors in developing countries.

Introduction

Defined as the capture of fish that do not constitute a fishers' dominant source of protein and are generally not sold or traded at market (FAO 2012), recreational fishing is a highly diverse activity, encompassing numerous gears, methods, and objectives. Recreational fishing is currently recognized as the dominant use of fish stocks in freshwater areas of highly developed nations (Arlinghaus et al. 2002; Cooke et al. 2015), and is practiced by approximately 10% of the population in these countries (Arlinghaus et al. 2015). Conservative estimates suggest that over US $190 B in expenditures are generated annually (World Bank 2012) through annual capture and harvest or release of over 30 billion fish (Cooke & Cowx 2004).

While recreational fishing is known to occur around the world, small-scale fishing activities continue to provide the dominant source of income (FAO 2016) and protein (Hall et al. 2013) for millions of people in developing countries. The dominant subsistence and small-scale capture fisheries in developing countries will likely face other challenges not characteristic of recreational fishery development, including issues of food security, access to markets, ecological and social responses to climate change, and the nature of governance and rights allocation in modern and often globalized fisheries, amidst increasing levels of competition for diverse resources, including with growing recreational fisheries (Andrew et al. 2007; Allison et al. 2009, 2012; Tacon and Metian 2009). Therefore, the likely growth of the recreational fishery sector in developing countries raises questions of equity rarely discussed in the literature on recreational fisheries (FAO 2012).

Research on recreational fisheries in highly developed countries has identified common potential and realized benefits and impacts associated with the sector. Benefits derived from recreational fisheries include substantial economic benefits in the form of expenditures and related infrastructure (Potts et al. 2009; Cisneros-Montemayor and Sumaila 2010), a potential increase in the stability of the employment buffer through increased seasonal or year-round employment via tourism (as diversification for accumulation, Smith et al. 2005), psycho-social benefits (Fedler and Ditton 1994; Floyd et al. 2006; Parkkila et al. 2010), and recreational fisher participation in conservation efforts such as citizen science, habitat restoration, and research (Granek et al. 2008; Tufts et al. 2015; Copeland et al. 2017). The risks associated with recreational fishing are multi-faceted and often coincide with other industries and environmental threats, rendering the role of recreational fishing and the degree to which it contributes to these risks difficult to quantify. Overfishing (Post et al. 2002, Post 2013), impacts on target species genotype (e.g., through selective mortality, Lewin et al. 2006) and behaviour (e.g., Cooke et al. 2007, Arlinghaus et al. 2017a), ecological degradation (through habitat loss and alterations to structure, Lewin et al. 2006), and introduction of invasive species (Johnson et al. 2009) have been identified as some of the key impacts occurring in the sector, in addition to conflicts with other fishing sectors over access to fish and space (Arlinghaus 2005). Important social and cultural conflicts may arise during recreational fishery development, as participants from different sectors may target the same species or adopt varying strategies to catch or consume fish (Ditton et al. 2002; Bower et al. 2014; Øian et al. 2017). This can culminate in cultural clashes where, for example, foreign tourists practice catch-and-release, while local values and custom resent this practice of catching fish "for fun" rather than for subsistence and survival (Arlinghaus et al. 2012).

The benefits and impacts associated with recreational fisheries as well as the tight coupling of the social and ecological systems create a general context that includes biological, environmental, social, governance, and economic attributes. Thissuggests that fisheries managers will need to adopt inter- and possibly trans-disciplinary approaches to maximize benefits derived from recreational fishing and minimize associated risks and impacts on other sectors (e.g., complex adaptive social-ecological systems approach, Arlinghaus et al. 2016, 2017b). Yet, there is currently very little information available about recreational fishery development in developing areas of the world, rendering evidence-based management a challenge (Aas 2002; exceptions include Friere et al. 2016). With this in mind, I conducted an online survey of recreational fisheries managers and personnel working directly with recreational fisheries in 132 countries described by the UN as having a low to high HDI score (all 51 countries with very high development were excluded from the survey; Figure 2.1) to identify perspectives and priorities associated with the growth of recreational fisheries in the developing world. I used the UN HDI as a development measure as it combines three dimensions (health, education, and standard of living) consisting of multiple indicators to derive a more robust measurement of overall development than gross domestic product alone (UN 2015). It is important to note that while there is no official definition of the term ‘developing countries’ (United Nations [UN] 2006), the World Economic Situation and Prospects group of the UN uses the terms ‘developed economies’, ‘economies in transition’ and ‘developing countries’ as the three broad categories describing the relative economic situation (and associated indices) of all countries (UN 2017). For sake of consistency in definition, I will employ these same terms herein. Specifically, I will consider countries with UN Human Development Index (HDI) scores ranging from low to high and excluding those with very high HDI scores to represent both economies in transition and developing countries, as the 64 countries described as highly developed by the UN (UN 2006) correspond closely with the 51 countries listed as having very high HDI scores. The very high

HDI score grouping is smaller as the information required to compute the index is not available from each highly developed country.

In this survey, I asked respondents to identify which management, policy, and knowledge gaps need to be addressed to support sustainable recreational fishery development. I also asked respondents to provide information on key attributes of their countries' recreational fishing sector, how recreational fisheries are perceived in these countries, and how this sector interacts with subsistence and commercial fisheries with a focus on identifying areas of conflict.

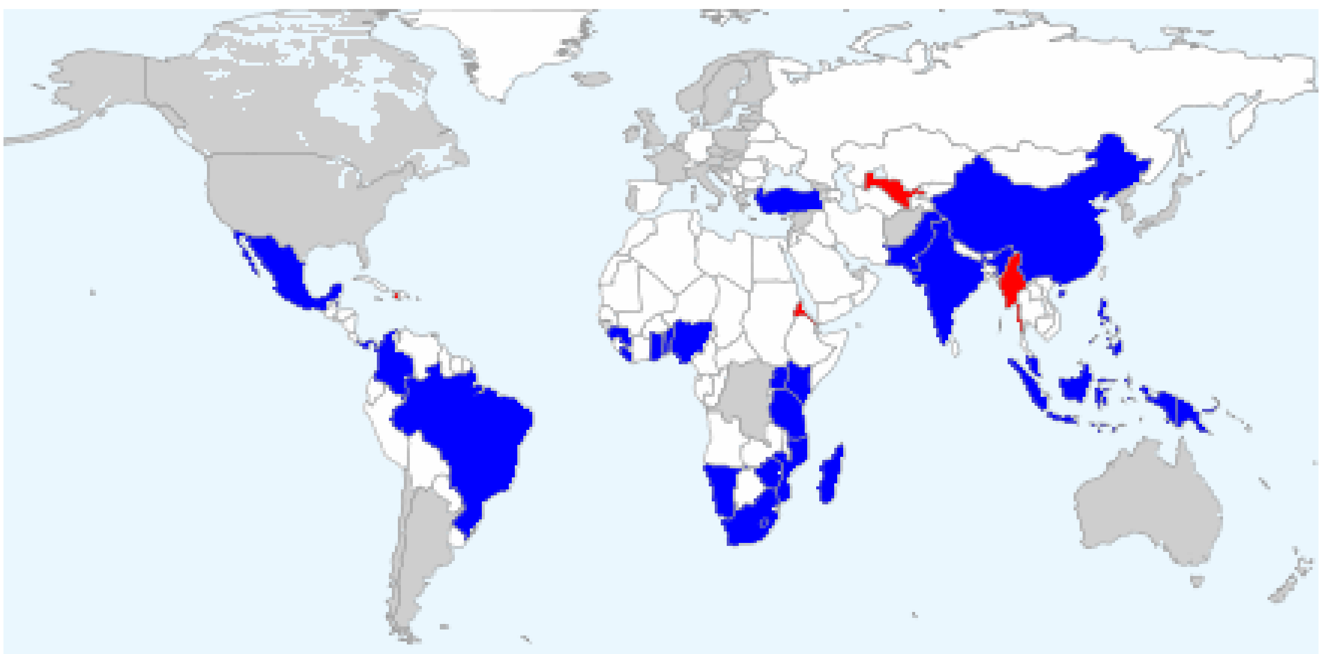

Figure 2.1 This global map shows countries excluded from the survey (those which scored 'very high' in the UN HDI) in grey. Countries from which responses were not received are indicated in white. Countries where respondents supplied online survey responses are coloured in blue and those where respondents replied to the survey in writing only are indicated in red.

Methods

Identification and Communication with Respondents

Individuals with knowledge of management of recreational fisheries in their country were the target population for the survey, including individuals whose work experience in fisheries management occurred at the international scale. Potential respondents from the target population were identified through online searches of international-scale fisheries programs (e.g., regional fisheries bodies of the FAO), and/or whose email contact information was available through national- or state-level fisheries departments, non-governmental organizations (NGOs), and university websites. Online searches of national- and state-level fisheries departments, fishing NGOs, and university fisheries research websites were conducted for each of the 132 countries on the UN HDI list ranked from low to high, and individuals with relevant expertise and available, active email addresses were contacted with an email invitation to participate. Out of respect for areas undergoing conflict, certain countries were excluded from communications that would otherwise have been included, namely Syria, Sudan, and the Democratic Republic of the Congo.

After confirming email address functionality through the invitation process, the survey was emailed to potential respondents in two waves over an 18-month period. The first wave of the survey ran from January 2013 to January 2014 and the second from February to June, 2014. In both waves, reminders were issued on a bi-weekly basis until no further responses were forthcoming.

Survey Construction and Rationale

The 13-question survey (Ethics approval 13-1355, Carleton University, Canada) was conducted in English only to avoid compounding potential language bias through multiple language translations (Appendix i). The survey was constructed to elicit responses without prompting respondents with key words or contextual cues, thereby reducing the likelihood of measurement bias associated with lack of topic knowledge (Newing 2010; Dillman et al. 2014). To reduce error associated with language bias, terms used in the survey were accompanied by operationalized definitions (Appendix ii).

The survey was organized around three categories: demographic questions describing the respondent, closed-ended questions to elicit respondent perspectives and attitudes, and open-ended questions to identify perceived needs in more detail. Demographic questions were used to ascertain respondents' country of employment, area of expertise, years employed in fisheries, and breadth of expertise (i.e., local to international). Closed-ended questions asked for perspectives relating to the importance of recreational fisheries to other sectors, and the extent and modes of national participation in recreational fisheries. Each closed-ended question using a six-point Likert agreement scale included for a response of 'I don't know' as a neutral option (Likert 1932). Questions designed to elicit responses that were not perspective-based (e.g., the number of participants in a fishery as factual statement) included requests to indicate the degree of certainty of the response and a request for references if available. Open-ended questions asked for respondents to prioritize management and policy needs, knowledge and development gaps, to describe existing management strategies, and indicate areas of potential conflict. These questions asked respondents to list the top three items they felt were most important for each category. A final question asked for any additional comments respondents wished to add pertaining to issues they felt were unique to the recreational fisheries in their country. Respondents were free to answer as many or as few questions as they wished; as such, the sample size of responses is presented for individual questions.

Data Management and Analysis

Direct comparison of responses between countries is not advisable due to culturally-based differences in perception and differences in language usage (OECD 2013). Thus, respondents were binned into a global pool for analysis. There was a small number of respondents (N = 9) who were unable to complete the online survey due to language or technical difficulties and so opted to provide as much information as they were able via email. In these circumstances, information provided by respondents that aligned with specific questions was included in the analysis of that question and is indicated as a written response in the results.

Analysis of the survey responses was performed according to question type. Descriptive statistics were generated for demographic questions and closed-ended questions. Closed-ended questions were also compared qualitatively among HDI ranks (low, medium, high). This was accomplished by treating the ordinal, Likert-type data as interval (assuming equal intervals, Ziberna et al. 2004) and conducting and performing hierarchical (bottom-up) cluster analysis using the 'rattle' package in R (Williams 2011). For this portion of the analysis, a non-response to a portion of a question was treating as a separate item on the Likert scale (i.e., 0), resulting in a Likert scale of 7 items (0 for no response, 1 – 5 for Likert scale items, and 6 for 'I don't know'). This inclusion allowed us to consider the similarity in non-response to specific questions among HDI-ranked respondent countries. In 12 cases, respondents were from the same country (e.g., two from Brazil, two from China); however, no two respondents from the same country shared the same demographic profile and the variation in response (see coefficient of variation, below) was consistent with variation between countries. As such, no weighting was applied by country.

The coefficient of variation (cv) was calculated as an indication of response variability for all closed-ended questions. Closed- ended questions (comparing frequency of Likert responses among HDI ranks) were analyzed in R (version 3.3.3, © 2016, The R Foundation for Statistical Computing, Vienna, Austria). Open-ended questions were analyzed in N-Vivo (version 10.0, © 2014, QSR International, Doncaster, Australia).

Open-ended responses were qualitatively analyzed for content following procedures described by Neuendorf (2017), wherein responses were coded by binning them into suggestion subject (categories) and then analyzed for frequency of occurrence. Each novel suggestion was catalogued and formed an individual 'node'. Nodes could contain a single response if the suggestion was not repeated, or multiple responses if the same suggestion was supplied by multiple respondents. Nodes were then binned according to subject category. For example, responses that knowledge of target species' biology, habitat usage, or trophic level represented key knowledge gaps would be counted as three nodes included under the broader subject category of 'target species life history'. The subject categories containing the highest number of nodes were considered to reflect respondent priorities. In the case of a tie, the subject category containing nodes with the most agreement (highest number of responses per node) were assigned priority.

Results

Response Statistics

Of the 809 potential respondents identified, 278 proved to be unreachable due to incorrect or non-functioning email addresses, leaving 531 remaining potential respondents. Each of these potential respondents received a survey invitation, and 136 potential respondents went on to view the survey. Of these, 75 respondents went on to complete the survey (online: 66, email correspondence: 9), resulting in an overall response rate of 14% (all potential respondents).

Respondent Demographics

Survey respondents represented 39 countries with HDI (UN 2015) scores ranging from 0.42 – 0.79 (Figure 2.1; Table 2.1) and seven countries without an HDI rank. Of the HDI-ranked respondent countries, 15 countries with high HDI scores (0.701 – 0.796), 13 countries with medium HDI scores (0.550 – 0.699), and 11 countries with low HDI scores (0.352 – 0.541) were represented. The respondents from seven countries that were not ranked on the HDI list were included in descriptive statistics and qualitative analysis but excluded from HDI-based analysis.

Respondents (N = 65) were from a variety of fields of expertise in fisheries: management (33.8%, N = 22), research (27.7%, N = 18), tourism (12.3%, N = 8), data collection and management (10.8%, N = 7), policy (7.7%, N = 5), enforcement (4.6% N = 3), education (1.5%, N = 1), and legislation (1.5%, N = 1). Respondents tended to have many years of experience in their respective fields (N = 65). Most respondents selected either over 20 years of experience (43.1%, N = 28) or 15-20 years of experience (18.5%, N = 12).

Table 2.1 Respondent Country UN Human Development Index Scores and rank (1 – 188), where 'NA' refers to a country with an unavailable score. Countries with unavailable scores were included in the survey based on GDP alone, but excluded from HDI-based analyses.

Respondent Country	**HDI Score**	**HDI Rank**	**Respondent Country**	**HDI Score**	**HDI Rank**
Bahamas	0.79	58	Kiribati	0.59	137
Panama	0.78	60	Ghana	0.58	139
Malaysia	0.78	59	Kenya	0.55	146
Seychelles	0.77	63	Pakistan	0.54	147
Turkey	0.76	71	Tanzania	0.52	151
Thailand	0.73	87	Nigeria	0.51	152
Saint Kitts and Nevis	0.75	74	Papua New Guinea	0.51	154
Mexico	0.76	77	Zimbabwe	0.51	154
Brazil	0.76	79	Solomon Islands	0.51	156
Fiji	0.73	91	Madagascar	0.51	158
China	0.73	90	Uganda	0.48	163
Tonga	0.72	101	Togo	0.48	166
Dominica	0.72	96	Benin	0.48	167
Colombia	0.72	95	Liberia	0.43	177
Belize	0.72	103	Mozambique	0.42	181
Maldives	0.71	105	Guinea-Bissau	0.42	183
Indonesia	0.68	113	Wallis and Futuna	NA	NA
Philippines	0.67	116	Montserrat	NA	NA

South Africa	0.67	119	Turks and Caicos	NA	NA
Namibia	0.63	125	Marshall Islands	NA	NA
Fed. States of Micronesia	0.64	127	Martinique	NA	NA
India	0.61	131	Cook Islands	NA	NA
Vanuatu	0.59	134	Anguilla	NA	NA

Perspectives Relating the Importance of Recreational Fisheries to Other Sectors

Respondents were more likely to respond to the request to rank commercial, subsistence and recreational fisheries sectors for social and economic importance (N = 63 for both categories) than they were to rank these same sectors for biological/ecological impact (N = 50). Commercial fisheries were most commonly viewed as being ecologically impactful (very important [65%], cv = 0.14), economically important (very important [63%], cv = 0.20), and socially important (very important [57%], *CV* = 0.19). Similarly, subsistence fisheries were most commonly viewed as very important in all categories: socially important (very important [52%], cv= 0.26), economically important (very important [40%], cv = 0.32), and ecologically impactful (very important and somewhat important [26%], cv = 0.35). Recreational fisheries were considered the least important of all sectors, but were still considered somewhat important or very important by most respondents: socially important (somewhat or very important [49%], cv = 0.40), economically important (somewhat or very important [43%], cv = 0.42), and ecologically impactful (somewhat or very important [38%], cv = 0.37).

When considering the relative importance of each fishery sector by zone, the majority of respondents indicated that commercial fisheries were the most important sector in offshore (93%, cv = 0.34) zones. Responses indicating the most important sector in coastal zones was balanced between the commercial (51%, cv = 0.40) and subsistence sectors (42%, cv = 0.40). Subsistence fisheries were the most significant sector in freshwater (FW) zones by small margin (47%; commercial 42%, cv = 0.39). Respondents indicated recreational fisheries were the most important sector in some offshore (2%, cv = 0.34), coastal (7% (cv = 0.40), and FW zones (11%, cv = 0.39). When asked the degree to which recreational fisheries overlap with the primary fisheries sector in offshore, coastal, and freshwater zones, most respondents indicated there was a degree of spatial overlap (occupying the same waterbodies; sectors overlap somewhat [offshore 42%, cv = 0.42; coastal 48%, cv = 0.49; FW 39%, cv = 0.42]) and resource overlap (targeting the same species; sectors overlap somewhat [offshore 47%, cv = 0.42; coastal 49%, cv = 0.41; FW 42%, cv = 0.42]) in all three zones.

Extent and Modes of National Participation in Recreational Fisheries

Some respondents (N = 33) offered estimates for future increases or decreases in participation and harvest (Q4). These respondents indicated they expected considerable increases in both participation and harvest rates in their national recreational fisheries (participation: 41%, cv = 0.70; harvest: 34%, cv = 0.68). Current participant (i.e., recreational fisher) characteristics were described by respondents per zone as mostly tourism-based (24%, cv = 0.56) or entirely tourism-based (21%, cv = 0.56) in offshore recreational fisheries, equally tourism-based or resident-based (35%, cv = 0.38) in coastal recreational fisheries, and mostly resident-based (27%, cv = 0.35) or entirely resident-based (22%, cv = 0.35) in FW recreational fisheries (Fig.2).

Respondents (N=46) also described the overall practices used by recreational fishers in their countries as mostly or entirely harvest-oriented (48%, cv = 0.49; mostly catch-and-release [24%], equally harvest- and catch-and-release oriented [15%]). When asked to describe the practices used by recreational fishers to catch the three most commonly targeted species in their countries, recreational fisheries were described by respondents as mostly or entirely harvest-oriented in all three zones (coastal [72%], cv = 0.65; FW [61%], cv = 0.44; offshore [58%], cv = 0.53; Figure 2.2).

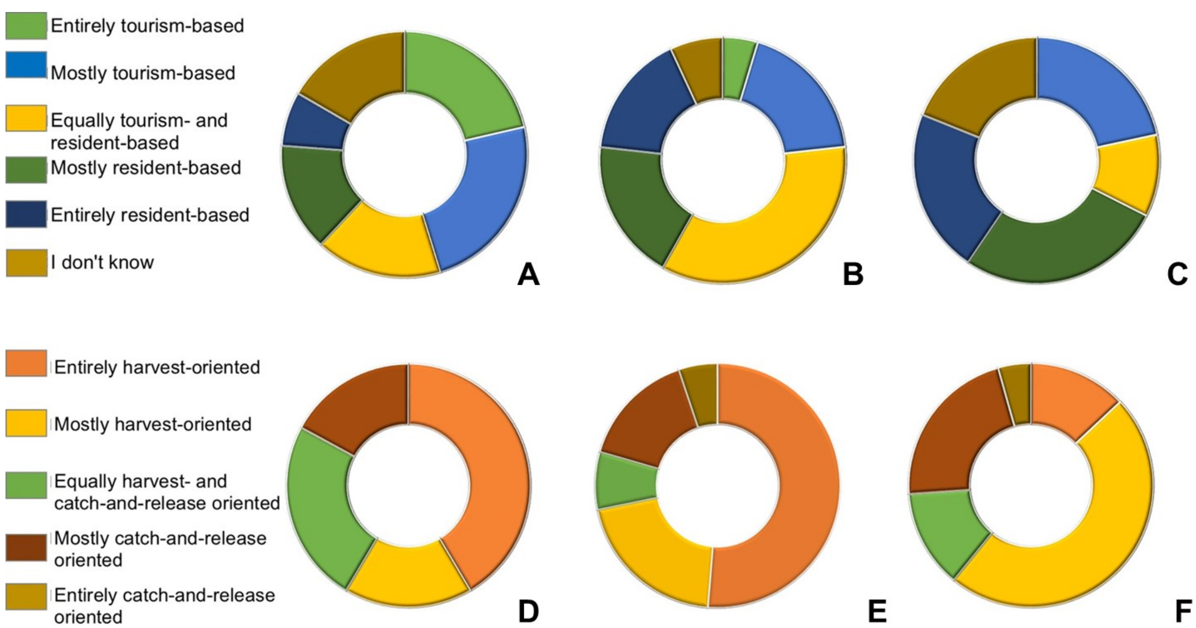

Figure 2.2 Respondent perceptions of recreational fishery attributes (ranging from entirely tourism-based to entirely resident-based) are shown at top for offshore (A), coastal (B), and freshwater (FW; C) zones. Respondents estimated recreational fisher behaviour (ranging from entirely harvest-based to entirely catch-and-release) in each of these zones, shown at bottom as offshore (D), coastal (E), and FW (F).

Comparing Responses Among High-, Medium-, and Low-HDI Ranked Countries

Hierarchical cluster analysis indicated that there was some similarity in closed-ended question responses among countries with similar HDI-ranked groupings (high, medium, low); however, the predictive power was not strong (Table 2.2). The confusion matrix used to evaluate the strength of the association of the hierarchical cluster indicated that clustering was more likely to predict all responses as originating from low HDI-ranked countries, which was the most effectively predicted group (Table 2.2). Low HDI-ranked country respondents were more likely to view recreational fisheries as unimportant, while the highest HDI-ranked countries were less likely to view recreational fisheries as unimportant (Q1). Both low and high HDI-ranked countries were more likely to predict strong growth in recreational fisheries harvest (Q4).

Table 2.2 A confusion matrix assesses the ability of clustering algorithms to correctly predict the HDI rank categories of respondent countries. The column headings indicate the number of clusters, the row headings indicate the actual groupings, and table body shows the number of responses assigned to each cluster. For example, there were 27 measurable responses provided by respondents from high HDI-ranked countries. Of these, seven were predicted correctly, nine were incorrectly predicted as responses from medium HDI-ranked countries, and 11 were incorrectly predicted as responses from low HDI-ranked countries.

		Predicted		
		1	**2**	**3**
Actual	High HDI Rank	7	9	11
	Medium HDI Rank	2	6	9
	Low HDI Rank	4	2	9

Prioritizing Management and Policy Needs, Knowledge and Development Gaps

Open-ended questions received fewer responses than closed-ended questions. Respondents to Q8 (N = 28) and Q9 (N = 26) were asked to rank top three priorities for management and policy needs, and knowledge and development gaps (Table 2.3). Eight subject categories were identified in responses prioritizing management needs, six for policy needs, seven for knowledge gaps, and six for development gaps (Table 2.3). Addressing data deficiencies through data collection occurred as a priority response for both Q8 (Management Needs) and Q9 (Knowledge Gaps). Other major themes included socio-economic assessment and regulation enforcement. Responses included within a node were sometimes contradictory, as different respondents recommended contrasting strategies to address similar problems, e.g., focusing on decentralisation versus nationalisation.

Table 2.3 Subject categories for open-ended questions according to subsection. Each subject category contained nodes representing shared and unique ideas identifying a theme (as described in the Methods section). The number of nodes contained in each subject category is shown in brackets after the subject category title. Subject categories containing the three highest numbers of nodes were identified as the top three priorities. The first, second and third priority subject categories are bolded, and the associated percentage of respondents who voted for each priority is included with the number of nodes in brackets.

Question, Section	**Subject categories**
Q8, Management Needs (54 suggestions)	**Begin data collection and management (N=17, 31%)**
	Develop or update legislation and regulations (N=14, 26%)
	Develop management plan (N=9, 17%)
	Improve management capacity (N=4)
	Develop conflict management strategies (N=3)
	Institute protected areas (N=3)

	Develop public education strategies (N=2)
	Promote recreational fishing (N=2)
Q8, Policy Needs (45 suggestions)	**Develop or update national policy (N=10, 22%)**
	Promote control strategies for recreational fisheries (N=10, 22%)
	Promote support policies for recreational fisheries (N=8, 18%)
	Improve administrative capacity (N=7)
	Adopt cooperation in recreational fisheries management (N=6)
	Update or reform legislation (N=4)
Q9, Knowledge Gaps (47 suggestions)	**Identify current state of recreational fisheries (N=20, 40%)**
	Measure impact of recreational fishing (N=13, 28%)
	Characterize life history attributes of recreational fish species (N= 7, 16%)
	Identify recreational fishing locations (existing and potential; N=3)
	Identify best practices (N=2)
	Identify fishery-appropriate management systems (N=1)
	Train staff in recreational fisheries management (N=1)
Q9, Development Gaps (40 suggestions)	**Develop physical infrastructure supports (N=9, 23%)**
	Develop enforcement systems for recreational fisheries (N= 7, 18%)
	Develop management institutions for recreational fisheries (N=7, 18%)
	Improve collaboration among recreational fisheries organizations (N=6)
	Develop economic management systems for recreational fisheries (N=6)
	Develop research programs to generate recreational fisheries data (N=5)

Areas of Potential Conflict

When asked to identify any issues that may serve to constrain the sustainable development of recreational fisheries in their respective countries, respondents (N = 26) were almost evenly divided, with 42% (N = 11) of respondents suggesting there were no priority issues constraining sustainable development of recreational fisheries. The remaining 58% (N = 15) indicated that the top issues constraining the sustainable development of recreational fisheries in their country were resource or spatial conflict among fishing sectors (31%, N = 5), and concerns regarding resource limitations (27%, N = 4) such as overharvest and coastal development.

Sources of potential and realized social, biological, and economic conflict were identified by respondents in Q12. All but three of the 32 suggestions could be categorized under two themes: potential and realized conflict among commercial and recreational fishers (63%, N = 20) and cultural conflict among recreational fishers and other recreational resource users (28%, N = 9). The potential and realized conflict among commercial, subsistence, and recreational fishers theme included nodes related to spatial competition (e.g., in preferred fishing areas, at fishing ports; N = 6), resource competition arising from shared target species (N = 5), and loss of commercial revenue to recreational fishing profits (N = 4). Concerns regarding conflict specific to recreational fishers congregating around commercial fish aggregating devices were also mentioned (N = 4). The cultural conflict among recreational fishers and other resource users theme included references to conflict between tourism- and resident-based activities (N = 4), and challenges related to the acceptability of catch-and-release practices (N = 4).

Discussion

The results of my survey reinforce the need to acknowledge recreational fisheries as a global fisheries sector and point towards important knowledge and development gaps that should be addressed to promote long-term sustainability of the activity. While recreational fishing is studied widely in much of North America, Europe, and Australia and New Zealand, i.e., highly developed economies, very few studies have been conducted elsewhere in the world, despite an increasing level of sector activity in many countries (Cooke and Cowx 2004; Bower et al. 2014; Barnett et al. 2016) and the potential for conflict among the different fishing sectors, as revealed by my survey. Findings from the cluster analysis indicate that respondents from higher HDI-ranked countries were more likely to view recreational fisheries as important than respondents from lower higher HDI-ranked countries, a finding which offers support for the concept that recreational fisheries grow concomitantly with economic freedom and associated leisure time (Smith 1986, FAO 2012). Cluster analysis findings also indicated that recreational fisheries in higher HDI-ranked countries may be more developed in offshore zones through non-resident tourism, and that recreational fisheries in low HDI-ranked countries may be growing primarily in freshwater zones through resident fishing activity, possibly indicative of availability of infrastructure and lack of access to suitable equipment for accessing an offshore marine environment. Although not definitive, these preliminary findings can be used to prioritize areas of focus for addressing knowledge gaps and data deficiencies.

The knowledge gaps identified by the respondents underline the severity of data deficiencies in the recreational fisheries of the developing world. All three top knowledge gaps described the need for baseline data (e.g., the population size and natural history of target species, the number and behaviour of recreational fishers, the amount of economic benefit accrued through recreational fishing activity). Data deficiencies accounted for the majority of knowledge gaps suggestions, making up 45 of 47 responses, while the related category 'data collection and data management' were considered the most important management need, making up 17 of 54 responses.

Data deficiencies do not apply solely to recreational fisheries occurring in developing countries, nor even just to recreational fisheries globally (see Lorenzen et al. 2016 and Bartley et al. 2015 on data issues in inland fisheries). Policy makers at the international level have expressed concern about the lack and quality of data available to support policy decisions (see FAO 2010, CEFAS 2013 for examples of regional- and national-level data deficiencies; see de Graaf et al. 2011 and Lorenzen et al. 2016 for discussion of data deficiencies related to small-scale fisheries). This trend appears to be increasing, with omissions of reported catches from fisheries and of distinct species on the rise (Bartley et al. 2015). Attempts are underway to account for data quality issues in fisheries catch reporting using multiple data sources and including reference to recreational fisheries (Paul and Zeller 2016), while some European countries provide estimates for recreational fishing catches (but again mostly economically important species such as salmon) to the FAO, few other countries do so (Bartley et al. 2015). Similarly, Cooke and Suski (2005) noted that catch-and-release research findings related to recreationally fished species tend to be limited to highly economically profitable species, particularly those fished in North America. Addressing data deficiencies should thus be considered a priority for recreational fisheries research.

Respondents framed similar responses to all open-ended questions from differing biological, social, and economic perspectives, demonstrating the multidisciplinary nature of recreational fishing attributes and issues. For example, respondents agreed on sources of conflict in recreational fisheries, but framed them differently as social, ecological, and economic context. Indeed, respondents were more likely to rank all fishing sectors (commercial, subsistence, recreational) in terms of social and economic importance rather than biological/ecological importance. Applying a social-ecological systems lens to recreational fisheries not only facilitates study and understanding of complex linkages among recreational fisheries system attributes (Arlinghaus et al. 2016), but encourages the consideration of variation in cultural values, norms, and traditions that have rarely been explored in the context of recreational fisheries (see Barnett et al. 2016; see also Schroeder et al. 2008 for an examination of culturally based differences in recreational fisher motivation). In addition to accounting for social and cultural diversity, applying a social-ecological systems approach to recreational fisheries research will serve to identify critical variables and manage overarching social-ecological processes (Arlinghaus et al. 2017b).

The perceived importance of harvest-oriented recreational fisheries to respondents, particularly in the freshwater and coastal fisheries, highlights the potential for recreational fishing to act as a source of additional nutrition in responding countries. A review of recreational fisheries contributions to nutrition by Cooke et al. (In Press) suggested that while the proportion of recreational fishing harvest to total harvest varies widely within and among regions (e.g., 24.5 % in Greece, 13.0 % in Argentina, 10.0 % in USA, 0.4 % in Senegal), recreational fishing can be found to contribute substantially to total fish harvest rates overall. Despite a clear harvest orientation in respondent countries, there were also reports of catch-and-release activities even in the resident fisher-dominant freshwater fisheries. This may, in some areas, be attributed to mandatory catch-and-release associated with regulations (e.g., in some parts of India; Gupta et al. 2015). In other areas, this evolution is most likely due to an increase in economic prosperity and growing middle class and the concomitant decrease in reliance on fishing activities for the immediate protein needs of the population. It is also possible that catch-and-release behaviour evolved along with the introduction of some sport fish species (e.g., rainbow trout, *Oncorhynchus mykiss;* tucunarés, *Cichla* spp.), which are perceived to be “valuable” sport fishes that are worth protecting.

The current fisheries management paradigm in many developing countries favours the marine small-scale commercial sector over recreational fisheries because of the assumed superior economic and social benefits associated with commercial fisheries. However, the additional perception that recreational fisheries are inconsequential because the activity is driven by choice rather than by necessity needs to be challenged. Several studies have demonstrated that recreational fisheries can provide considerable economic benefits (e.g., Shresta et al. 2002; Potts et al. 2009; Cisneros-Montemayor and Sumaila 2010; World Bank 2012), even potentially exceeding those of commercial fisheries. These economic benefits may accrue directly to local people through the provision of jobs as service personnel in resorts (Potts et al. 2009), angling guides, and the charter of commercial vessels (Pawson et al. 2008). If these recreational fisheries are dominated by catch-and-release angling practices (e.g., Potts et al. 2009) these benefits can be obtained with limited resource competition between sectors. However, despite limited resource competition, perceived competition for space between recreational and commercial fisheries is likely to be very real and will have consequences for social behaviour and thus needs to be properly managed.

The life-cycle of fisheries metaphor predicts that in economically less developed countries small-scale commercial and subsistence fisheries dominate over recreational fisheries, but the importance of recreational fisheries rises as economic development evolves (Smith 1986; Cowx et al. 2010; FAO 2002). My findings align with the life-cycle of fisheries metaphor in that in developing countries the dominant fisheries are small-scale commercial and subsistence fisheries and not recreational fisheries. However, in all developing countries some level of recreational fishing activity was reported, and respondents thought the sector would grow, particularly in countries with higher HDI scores. Whether these survey results genuinely aligned with the model, and whether the model itself was a likely predictor for recreational fishery growth in the developing world was a source of some debate among my author group. While my findings accord with the theory that increased leisure time and economic growth might lead to growing recreational fisheries, it was acknowledged that this would not hold true in all cases or in all countries. Specifically, different countries have different perspectives on the value and importance of fisheries that may constrain recreational fishery growth in favour of policies promoting aquaculture, while in other cases recreational fisheries may remain a peripheral, tourist-oriented activity. Additionally, some consideration was given to trends such as urbanization, which could result in negative growth in recreational fisheries. Equally importantly, the discussion highlighted the need to address differences in culture as they pertain to fisheries more effectively in recreational fisheries research such that Western views and cultural norms are not preferentially endorsed as a result of comparative research abundance. This issue has widely been noted in the context of the difficulties in incorporating traditional or local ecological knowledge into data collection and interpretation (e.g., Huntington 2000; Berkes et al. 2013), but applies to recreational fisheries also.

Study Limitations

The results of this study represent the first effort to conduct a global survey of recreational fisheries professionals. Interpretation of the results must be considered within the limits of analysis based on a small sample size. Although language bias derived from the use of an English language survey was accounted for in the survey design and subsequent analysis (see Data Management and Analysis), other sources of bias and associated assumptions should be considered. For example, I assumed and accepted responses to demographic questions as true. However, I suggest that the likelihood of any deception is limited given the anonymity of the survey; furthermore, any impacts of demographic exaggeration would be minimal as demographics did not contribute to analysis. Additionally, although all countries having an HDI of low to high were targeted, there was a distinct lack of response from the northern region of Africa and a high response rate from island nations, a source of geographic bias that may have also resulted in a bias towards marine and possibly offshore recreational fisheries.

I attempted to reduce as many sources of error as possible, but acknowledge that given the language limitations and the impossibility of locating every professional responsible for managing recreational fisheries in developing countries, combined with the degree of non-response, unknown degrees of coverage and sampling errors will have occurred. Thus, my results should be viewed as a preliminary assessment and a first step, rather than an exact characterization of developing world recreational fisheries. Nonetheless, what is clear is that recreational fisheries are important in developing countries and the identified knowledge gaps and management needs should be addressed in a timely manner to foster sustainable development.

Conclusion

Viewing recreational fisheries through a global lens can help to identify large-scale issues and processes, but management actions taken at the local level will require a social-ecological systems approach. Recreational fisheries have the potential to act as an important contribution to livelihoods through their development, but certain factors such as engagement and sharing of economic benefits must be in place to ensure sustainable growth that can both benefit local communities and limit the negative impacts of recreational fishing activity (Barnett et al. 2016). Research can support the sustainable development process by providing quantitative evidence on which to base management decisions, working with communities to gather data (e.g., through economic and catch assessments) to support policy development, and by engaging the recreational fishing and broader community in conservation and sustainable use of shared resources. To date, however, research has not kept up to the growth of the recreational fishing sector in the developing countries. The field now requires a genuinely multicultural and interdisciplinary approach to incorporate the interests and needs of a truly global industry (Aas 2002).

Chapter 3. Involving recreational fisheries stakeholders in development of research and conservation priorities for mahseer (*Tor* spp.) of India through collaborative workshops

Abstract

The mahseer (*Tor* spp.) of India are a group of potamodromous cyprinids currently facing numerous challenges in their native ranges including overfishing, pollution, and hydropower development. As a result of such challenges, four of the seven Indian species of *Tor* have been listed as 'Endangered' on the IUCN Red List, including two of the most popular recreationally fished species, *Tor khudree* and *Tor putitora*. Stakeholders in the mahseer recreational fishery may serve as an ally for this group of iconic fishes, fostering aquatic stewardship and providing livelihood alternatives for poachers. Yet, information regarding species-specific responses to recreational fishing practices is lacking and a 2009 decree equating fishing with hunting in the Indian Wildlife Protection Act (1972) has since 2011 effectively banned angling within protected areas and rendered the future of mahseer recreational fisheries elsewhere uncertain. In 2014, I collaborated with local organizations, fisheries professionals, non-governmental organizations (NGOs), and anglers to conduct two stakeholder workshops designed to develop a research agenda for various species of Indian mahseer. General knowledge gaps identified in the two workshops were very similar and included biological, sociological, and economic considerations. The resulting research priorities in both locations strongly highlighted local context, indicating that while opportunities for addressing knowledge gaps through collaboration exist at the national scale, there is a need for regional- or fishery-specific governance strategies and approaches to mahseer research and conservation.

Introduction

Stakeholder engagement, the active participation of individuals in planning, research, or management processes that impact them (Sloan 2009), has become a popular topic in fisheries research (e.g., in the US, Feeney et al. 2010; in the UK, Hartley and Robinson 2008; in Europe, Mackinson et al. 201; for spatial planning, Pomeroy and Douvere 2008). A number of concerns associated with the incorporation of stakeholder engagement into research have been identified (e.g., negative impacts on scientific integrity, Abbott and Guijt 1997; the potential exclusion of already marginalized groups from the engagement process, Kothari 2001; Prell et al. 2008; potential consequences of negative trust relationships, Smith et al. 2012). Other studies, however, have noted that incorporating local context led to improved research outcomes as a result of access to more relevant information (e.g., anticipating problems or conflict, Koontz and Thomas 2006; facilitating social learning Steyaert et al. 2011; promoting trust among collaborators, Yochum et al. 2012). These benefits may be critical for developing sound management strategies for data deficient recreational fisheries. For example, Arlinghaus and Krause (2013) suggested that under certain conditions stakeholder estimates of population size could be as reliable as more traditional stock assessment methods. Other benefits associated with the stakeholder engagement process include improved relationships between researchers and the public, the development of ongoing partnerships, and acceptance and self-enforcement of management decisions based on research outcomes (Reed 2008, Steyaert et al. 2007).

Recreational fisheries have been recognized as a complex social-ecological system, where changes to either component results in changes to the other (Mora et al. 2009). In these systems, wicked problems, or problems that by their nature are difficult to solve due to a combination of complexity and stochasticity, can arise which require extensive communication and efforts among numerous disciplines to tackle effectively (Jentoft and Chuenpagdee 2009). Stakeholder engagement and partnership strategies have proven successful in recreational fisheries research and conservation efforts by incorporating multiple viewpoints and facilitating angler participation to engender cooperation and support (e.g., see Armitage et al. 2008; Granek et al. 2008; Hartley and Robertson 2006). Indeed, when consultation and participatory conditions are met, harnessing the support of freshwater and marine anglers can contribute greatly to aquatic stewardship (Cowx et al. 2010; Granek et al. 2008; Tufts et al. 2015; but see also Danylchuk and Cooke 2011).

An example of this potential can be found in the management and conservation challenges surrounding the mahseer (*Tor* spp.) recreational fishery of India. Mahseer are a group of large-bodied potamodromous cyprinids targeted by commercial, subsistence and recreational fishers in Asia. Despite the fact that four of the seven *Tor* species in India have been listed as endangered (an additional species is listed as ‘Near Threatened’, IUCN 2015), very little information is currently available describing the ecology of these species (but see Bhatt et al. 2004; Bhatt and Pandit *In Press*; Nautiyal et al. 2008; Nautiyal 2013 describing migration behaviours and ecology of *Tor putitora*). Catch and release (C&R) was advocated as an angling ethic in the 1970s to control poaching activities after anglers noted a decline in the body size and rate of catch (Gupta et al. 2015a). To mitigate concerns surrounding the state of the fishery, anglers developed ‘coalitions’ and leased property along river reaches, developing training programs for guides and monitoring river activities to reduce poaching (Everard and Kataria 2011; Gupta et al. 2015b; Pinder and Raghavan 2013). Angler catch data collected from a former angling camp on the Cauvery River has demonstrated an increase in catch rate (along with concomitant decreases in body size), indicating strong recruitment has occurred since this type of fisheries management model was established (Pinder et al. 2015b). However, in 2009, a legislative decree equating C&R fishing with hunting effectively shut down the recreational fishery in protected areas, while leaving other locales virtually unaffected. This uneven application of regulations has since resulted in anecdotal reports of elevated poaching and illegal fishing activity within the Cauvery Wildlife Sanctuary (Pinder et al. 2015a, 2015b).

In 2013, WWF India issued a report detailing the status and challenges surrounding mahseer conservation (see WWF India 2013). A key report finding was the need to develop an evidence based research agenda to support mahseer conservation. In 2014, I collaborated with local organizations, fisheries professionals, NGOs, and anglers in two regions to conduct stakeholder workshops designed to meet this need by facilitating discussions to clarify the current state of mahseer research, identify key knowledge gaps constraining mahseer conservation, and to develop a research agenda based on the outcomes of these discussions.

Methods

The goal of both stakeholder workshops was to collaborate with researchers, industry and stakeholder partners to identify key knowledge gaps and develop a research agenda for mahseer that addresses these knowledge gaps and supports current and future research and conservation efforts. The unique characteristics of each location, and associated fisheries, threats, and focal species necessitated different approaches for each workshop. In both cases, preparation consisted of identifying local experts in the target areas to seek their partnership in facilitating workshops through planning and participation (as per Reed et al. 2006). These facilitators populated a balanced list of key stakeholders from multiple arenas, including fisheries and forestry managers (Karnataka Department of Fisheries, Uttarakhand Department of Forests and Ecotourism), representatives from fishing associations (including the Coorg Wildlife Society, the Wildlife

Association of South India, Jungle Lodges, The Himalayan Outback, Baobab Educational Adventures), lodge and homestay owners, anglers, and representatives from conservation NGOs (WWF India and Zoo Outreach Organization).

The South India workshop took place at Jungle Lodges and Resorts, Bannerghatta Nature Camp, Bangalore, Karnataka on March 28 and 29, 2014, with 30 people in attendance. Mahseer recreational fishing was firmly established in the southern states, including Karnataka (Gupta et al. 2015b; Sehgal 1999). Participants in this workshop were interested in discussing developments in the recreational fishery, including rules and regulations governing fishing activity, including the angling ban in protected areas. The North India workshop took place on April 5, 2014 at the Byasi Beach Camp, Rishikesh, Uttarakhand, on the banks of the Ganges River, and on April 6, 2014 at Atali Ganga, Rishikesh, Uttarakhand, with 18 people in attendance. Mahseer recreational fishing is growing as a tourism industry in the northern states (including Uttarakhand), though it is not known to be a popular activity undertaken by domestic recreational anglers. Participants of this workshop were interested in discussions regarding the role of tourism in promoting the sport, and strategies for achieving balance between tourism- and locally-based activities (e.g., small-scale commercial and subsistence fishing).

The nature and type of both workshops was developed in response to the preferences of participants and partners. For example, the workshop held in South India (Bannerghatta) was very structured, with specific time frames allotted for presentations and discussion. In North India (Byasi/Atali Ganga), the workshop process was more flexible, leaving more time for ad hoc discussions and deviations from planned topics. Time frames were estimated for individual topics and were adjusted according to how much/how little participants had to contribute.

Both workshops were scheduled over two days, with different goals set for each day. I opted to provide numerous opportunities for relationship-building and conversation prior to initiating discussion regarding the research agenda (as per Allen et al. 2011; Reed 2008). For example, on Day 1, participants identified local and regional-scale issues impacting mahseer, discussed the management and conservation context for these issues, and background topics associated with the research (i.e., current state of recreational fisheries research, C&R research and associated best practices; Figure 3.1, Figure 3.2). This method transformed the process from a top-down scenario to a bottom-up process in accordance with Reed's (2008) best practices for stakeholder engagement, and afforded the opportunity to discuss any potential flashpoint issues in an open atmosphere. These flashpoint issues were aired, but not considered an essential part of the research agenda by any attendees. The list of knowledge gaps was populated at the end of Day 1 in both workshops. The second day (Day 2) was devoted to developing a research agenda for mahseer based on knowledge gaps and discussion from Day 1.

Figure 3.1 Participants in the South India (Bannerghatta) workshop pose for a photo at the conclusion of Day 1.

Figure 3.2 Participants in the North India (Byasi) workshop during breakout discussions on Day 1.

Results

Stakeholder workshop participants identified knowledge gaps across disciplines (e.g., biological, sociological, economic). While similar points were recognized in both workshops, location-specific knowledge gaps were also identified (Table 3.1). Twelve knowledge gaps were identified by Bannerghatta workshop participants (5 biological; 4 sociological; 3 economic). Fifteen knowledge gaps were identified by Byasi/Atali Ganga workshop participants (6 biological; 7 sociological; 2 economic). Both locations shared similarities among five biological knowledge gaps, three sociological knowledge gaps, and one economic knowledge gap.

Table 3.1 Priority knowledge gaps constraining mahseer conservation identified by participants of stakeholder workshops in South India (Bannerghatta) and North India (Byasi/Atali Ganga). Knowledge gaps have been separated into categories according to primary concern: biological, sociological, and economic. Where identical knowledge gaps were identified, identical descriptors have been used. Where similar knowledge gaps were identified, descriptors highlight specificities according to each location.

	Bannerghatta Workshop	**Byasi/Atali Ganga Workshop**
Biological	Insufficient knowledge of: • Taxonomy and diversity of mahseer (and other freshwater fishes) • Natural history and ecology of mahseer, including differences among age/size classes re: physical habitat, habitat use, major life events, e.g., spawning, migration • Amount and impacts of illegal fishing activity, including use of small mesh nets,	Insufficient knowledge of: • Diversity of mahseer (and other freshwater fishes) • Natural history and ecology of mahseer, including differences among age/size classes re: physical habitat, habitat use, major life events, e.g., spawning, migration • Amount and impacts of illegal fishing activity, including use of small mesh nets, dynamiting, poisoning, and electrocution

	dynamiting, poisoning, and electrocution • Impacts of invasive species introductions, stocking, and C&R on mahseer, bycatch species (e.g., snakehead; *Channa* spp.), and compare potential tools for improving survivorship of released fishes • Impacts of hydropower development and pollution on mahseer populations and behaviour, e.g., impacts of reduced connectivity, shifting habitat types (lentic to lotic)	• Impacts on mahseer populations arising from invasive species introductions and stocking • Impacts of hydropower development and pollution on mahseer populations and behaviour, e.g., impacts of reduced connectivity, shifting habitat types (lentic to lotic) • Suitable levels of combined (i.e., among fisheries) harvest
Sociological	Insufficient knowledge of: • Identifiable cross-cutting and cross-jurisdictional issues • Identify effective methods for raising awareness of mahseer conservation, e.g., mahseer as umbrella species to promote freshwater conservation • Collaboration potential among managing entities • Impacts of angling behaviours on mahseer behaviour (e.g., bait use, ground-baiting)	Insufficient knowledge of: • Identifiable cross-cutting and cross-jurisdictional issues • Identify effective methods for raising awareness of mahseer conservation, e.g., mahseer as umbrella species to promote freshwater conservation • Collaboration potential for addressing community needs in the fisheries management context • Benefits and constraints of recreational fishing activity to local communities • Enforcement efficacy, and alternative strategies that promote safety and compliance

		• Suitable methods for generating community support for recreational fishing activities, including recruitment of young, female anglers • Suitable management toolbox for integrating different fishery types
Economic	Insufficient knowledge of: • Economic expenditures associated with all fishery types • Suitable access fees for recreational fishing activities • Efficacy of fees as enforcement for rule violations, suitable fine amounts	Insufficient knowledge of: • Economic expenditures associated with all fishery types • Suitable strategies for sharing benefits arising from recreational fishing activities with local communities

In both workshops, participants developed the list of top six research priorities from the established knowledge gaps. These identified priorities were also multi-disciplinary but exhibited fewer similarities than occurred through developing the list of knowledge gaps (Table 3.2). Both groups retained three of the shared knowledge gaps, but on refining them into more detailed research priorities differentiated greatly on focus (Table 3.2).

Table 3.2 Priority research agenda items identified by participants of stakeholder workshops in South India (Bannerghatta) and North India (Byasi/Atali Ganga). Research agenda items have been separated into categories according to primary concern: biological, sociological, and economic. Where identical research priorities were identified, identical descriptors have been used. Where similar research priorities were identified, descriptors highlight specificities according to each area.

	Bannerghatta Workshop	Byasi/Atali Ganga Workshop
Biological	Clarify the taxonomy and systematics of mahseer (and other endemic freshwater fishes) Quantify trends in natural history and ecology of mahseer, including: differences among age/size classes re: physical habitat; habitat use; major life events, e.g., spawning, migration; and mahseer population dynamics, including age, growth, reproduction, mortality (natural mortality rates and external sources such as angling) Determine impacts of invasive species introductions, stocking, and C&R on mahseer, bycatch species (e.g., snakehead; *Channa* spp.), and compare potential tools for improving survivorship of released fishes	Clarify the taxonomy of mahseer (and other freshwater fishes), confirm identification, and examine local adaptations (e.g., dietary overlap and competition among freshwater fishes) Identify impacts of hydropower development and pollution on mahseer populations and behaviour, e.g., impacts of reduced connectivity, shifting habitat types (lentic to lotic)
Sociological	Determine the suitability of mahseer to act as an umbrella species for freshwater conservation in India by determining the value of mahseer (and C&R) to the public, and identify other routes of knowledge mobilization	Determine the suitability of mahseer to act as an umbrella species for freshwater conservation in India and identify other mechanisms for encouraging conservation-oriented behavior Measure collaboration potential for addressing community needs in the fisheries management context, including determining the carrying capacity of local social systems for ecotourism and angling activities

		and identifying suitable models for facilitating social conflict resolution
Economic	Develop an estimate of the economic expenditures generated by recreational angling, trade-off/offsets Evaluate efficacy of fees as enforcement for rule violations, and identify alternate methods for regulation enforcement (e.g., discouraging the sale of mahseer at market)	Develop an estimate of the economic expenditures generated by recreational angling, and estimates for the degree of local dependence on mahseer for livelihood/food Evaluate suitable strategies for sharing benefits arising from recreational fishing activities with local communities, including the likelihood of success of alternative livelihood strategies

Discussion

The knowledge gaps and research priorities identified in both workshops highlight the need to establish research programs that acknowledge the integrated nature of fisheries, including multi-disciplinary approaches in research (a need also identified in Europe, Arlinghaus 2006), and addressing the requirements of location-specific stakeholders and sectors (e.g., balancing participation among different forms of tourism and fisheries). Indeed, workshop participants identified a greater number of sociological and economic knowledge gaps than biological knowledge gaps constraining mahseer conservation. The shared identified knowledge gaps indicate that there are opportunities to collaborate among states/regions to establish an evidence base for mahseer biology, ecology, and behaviour, in addition to opportunities for research studying the biological, social, and economic impacts of recreational (and other sector) fisheries.

Both groups prioritized the research agenda items based on local issues and concerns (i.e., context mattered) and no individuals or groups disagreed with any included items. For example, both groups identified impacts of invasive species and hydropower development as knowledge gaps, but on prioritizing issues for the research agenda, participants in the Bannerghatta workshop prioritized invasive species concerns over hydropower development, while participants in the Byasi/Atali Ganga workshop prioritized issues arising from hydropower development over invasive species. Bannerghatta workshop participants were interested in partnering with management entities to explore enforcement options and alternatives in an already established fishery, while Byasi/Atali Ganga workshop participants identified community engagement and benefit-sharing as a priority management strategy to build the mahseer fishery. These differences in priority setting highlight the need for multi-scale approaches (i.e., national and state) to fisheries research and management. Shared knowledge gaps (including impacts to mahseer by invasive species, hydropower development, illegal fishing methods, and the use of mahseer as an umbrella species to promote freshwater conservation) could be studied at the national level, while adopting management strategies based on research outcomes may benefit from a state- or location-level focus.

Regional-level differences in dominant mahseer species and ecology further support the need for multi-level mahseer research and management strategies. Recent research by Everard and Kataria (2011) and Gupta et al. (2014a) suggests that the golden mahseer (*T. putitora*) may be useful as a flagship species for promoting freshwater conservation throughout the Himalaya Rivers in Northern India, where this species is found (Nautiyal 2013). *T. khudree*, while endangered in its native waters (IUCN 2015), has been artificially cultured and since the 1970's been periodically introduced to the Cauvery. This intended augmentation of the stock is now strongly suspected to have played a role in the decline of the yet to be described humpback mahseer endemic to the Cauvery River in the South (Pinder et al. 2015a). These nuances indicate that while priorities for mahseer research (as identified by workshop participants) may be similar, there will be a need for species-specific approaches to sufficiently address the identified knowledge gaps.

The occurrence of mahseer species in different countries in Asia (e.g., *T. putitora*, Nguyen et al. 2008) suggests collaboration and cooperation may also be possible at the international level. Current research efforts examining the behavioural ecology of *T. putitora* in Bhutan (Claussen 2015) for example, could offer valuable insights for the same species in the Himalayan watershed across the border in India. Similarly, ongoing research efforts in India may be useful in supporting the development of research priorities for mahseer in other countries (e.g., in Malaysia, Nguyen 2008). As such, I suggest that international collaboration of mahseer researchers may be beneficial for aligning goals and strategies to identify synergies in research priorities and opportunities for collaboration.

The involvement of stakeholders in the research agenda development process was integral to identifying priority focal points that may have otherwise been missed, or possibly discounted. Through stakeholder participation, I was not only able to benefit from the varied perspectives and expertise of workshop participants, but incorporate regional and local priorities into goal setting in a manner that may not have been possible at a more formalized national meeting. It is essential to note that while I took care to invite individuals representing as many viewpoints as possible, a strong majority of the invitees viewed recreational fisheries positively, and none of the attendees were subsistence fishers, or members of migrant communities. As such, priorities of these communities may not be adequately represented in the respective research agendas (see Kothari 2001; Prell et al. 2008). The views of local communities and stakeholders vary among fisheries (e.g., see Gupta et al. 2014b). As such, I recommend that any future efforts to adopt research outcomes into management strategies include consultation with these stakeholder groups also.

This workshop process is an example of the overall value of stakeholder engagement for addressing data deficiencies in global recreational fisheries. Stakeholder engagement affords the opportunity to gather many perspectives together, thereby bringing more information to the table through which to develop a knowledge base (Hartley and Robertson 2008; Reed et al. 2008; Steyaert et al. 2011). Many recreational fisheries around the world are data deficient, and many managing bodies may be constrained in supporting fisheries research by limited expertise and funding (Mahon 1997). Creative approaches will be essential in addressing deficiencies effectively as we move towards improving global fisheries management and conservation using best available science. Several tools have been developed and used as a way of addressing such data deficiencies in recreational fisheries to ensure that we are not 'managing blind' (rapid assessments, Bower et al. 2016, Lennox et al. 2015; species-specific C&R research, see examples in Cooke and Schramm 2007, Cooke and Suski 2005), but to date these approaches have heavily favoured the biological responses of species to fisheries processes. There continues to be a dearth of suitable tools available for rapidly and thoroughly incorporating sociological and economic considerations in fisheries research (Arlinghaus 2005), though strategies for incorporating adaptive management and co-management processes are increasing in other fields (e.g., see Armitage et al. 2008; Mackinson et al. 2011; Pomeroy and Douvere 2008). Using effective methods of stakeholder engagement can help researchers to address data deficiencies by allowing researchers to incorporate local knowledge into priority and goal setting, and better understand the socio-economic context of specific fisheries.

<u>Chapter 4. Rapid assessment of the physiological impacts caused by catch-and-release angling on blue-finned mahseer (*Tor* sp.) of the Cauvery River, India</u>

Abstract

Forty-nine blue-finned mahseer (*Tor* sp.; mean total length 458 ± 20 mm) were angled using a range of bait/lure types, angling and air exposure times in water that averaged 27 ± 2˚C over the course of the assessment. No cases of mortality were observed, and rates of moderate and major injury were low, with 91% of mahseer hooked in the mouth. More extreme physiological disturbances (i.e., blood lactate, glucose, pH) in mahseer were associated with longer angling times. Sixteen fish (33%) exhibited at least one form of reflex impairment. Moreover, longer air exposures and angling times resulted in significant likelihood of reflex impairment. Findings suggest that blue-finned mahseer are fairly robust to catch-and-release, but that anglers should avoid unnecessarily long fight times and minimize air exposure to decrease the likelihood of sub-lethal effects that could contribute to post-release mortality.

Introduction

Recreational fisheries are increasingly recognized as an important fisheries sector around the globe (FAO 2012). Although anglers harvest some fish, catch-and-release (C&R; i.e., the act of returning a fish to water after landing, presumably unharmed; Arlinghaus et al. 2007), is common; it can be voluntary due to the conservation ethic of the anglers or a result of compliance with regulations that require fish to be released. The extent to which C&R behaviours practiced by anglers can act as a conservation tool in any fishery is a complex one, particularly when targeting endangered species (Cooke et al. 2016). Target species exhibit a wide-range of outcomes associated with C&R (i.e., various species respond differently to the same angling practices), suggesting research should be conducted on individual species to assess the suitability of C&R as a management strategy (Cooke and Suski 2005). For example, some species may demonstrate sensitivity to air exposure or exhibit high post-release mortality rates (see numerous examples in reviews by Muoneke and Childress 1994; Bartholomew and Bohnsack 2005; Arlinghaus et al. 2007). Even if data are available for species known to exhibit similar physiologies, findings may not be transferable to target species occupying different habitat types, life history stages or targeted using different angling behaviours (Cooke and Suski 2005).

Fishery-specific research can be challenging when resources for fisheries management or data availability are limited; an issue that may be of particular concern in developing recreational fisheries in low-to middle income countries (LMICs; Bower et al. 2014) or for endangered species (Cooke et al. 2016). Rapid C&R assessment protocols that combine injury and mortality observations with assessments of physiological state (see Cooke et al. 2013) and reflex impairment (see Davis 2010) have been developed as a way of generating data on such key response attributes in a swift and cost-effective manner. In a C&R rapid assessment, researchers first interact with stakeholders to identify likely areas to focus research efforts based on specific elements of a fishery (e.g., gear type, angler behaviour, environmental conditions) and then use a combination of simple endpoints to obtain a "snapshot" of the extent to which behaviours practiced in a given C&R fishery may be sustainable. By combining these approaches (i.e., injury and mortality assessment, physiological analyses, reflex indicators) into a single study to generate essential baseline data for species-specific responses to C&R practices, rapid assessments can also serve as a tool to triage future research priorities. For example, a rapid assessment could identify the need for a larger-scale assessment across multiple seasons if there is evidence of a thermal stress component or perhaps looking at different lure, bait or hook types should there be evidence of deep hooking. Essentially, a rapid assessment is the first step towards ensuring that C&R fisheries are sustainable and that angling practices are optimized to maintain the welfare status of fish that will be released.

Mahseer (*Tor* sp.) are a group of potamodromous cyprinids endemic to Asia. The mahseer of India are currently declining as a result of a multitude of pressures including changes in land use, agricultural run-off, hydropower projects, invasive species, overexploitation and use of damaging fishing gears (Raghavan et al. 2011; Everard and Kataria 2011; WWF 2013). Indian populations of the *Tor* mahseer consist of seven species yet identified in scientific literature, though there is still much confusion surrounding their taxonomy. Four known species are currently listed as 'Endangered' on the IUCN RedList (IUCN 2014), including the two most popular game species *Tor khudree* Sykes (blue-finned or Deccan mahseer), and *Tor putitora* Hamilton (golden mahseer). In India, these species are primarily targeted by subsistence and recreational fishers (Everard and Kataria, 2011; Raghavan et al. 2011). In the 1970's, recreational fishers first noted a decline in mahseer size and numbers and acted to address the problem, forming angling conservation groups and coalitions (e.g., Wildlife Association of South India (WASI)). These groups established angling camps based on strict C&R principles, employed guards to protect stocks from poaching and began collecting catch data (Pinder and Raghavan, 2013).

Despite the lengthy history of recreational fishing for mahseer in India, little is known about the responses of the species to common angling practices. Indeed, there are currently no known studies that have evaluated any elements of C&R practices (spanning injury, mortality, or stress) for any mahseer species in India or anywhere within their range. To address these knowledge gaps, working in partnership with local anglers and river managers, a rapid assessment was used to evaluate C&R practices for angled blue-finned mahseer (which will be referred to as *Tor* sp. to reflect current taxonomic uncertainty; also see Pinder et al. 2015) in the Cauvery River, India. Results of this study can be used to support evidence-based decision making in mahseer recreational fisheries, and the rapid assessment process can support the development of species-specific best practices for recreational fisheries in data-poor LMICs that can be communicated to anglers and other relevant stakeholders.

Methods

Study Site

Angling and sampling took place along the Cauvery (Kaveri) River (Ammangala Village, Valnur; 12.457494˚N, 75.960549˚E; Figure 4.1) in Kodagu District (Coorg), Karnataka State, India in March 2014. Angling on much of this stretch of river (exceptions include temple sanctuary waters and the Nisargadhama Reserve) is managed by the Coorg Wildlife Society

(CWS), an NGO that coordinates C&R angling in the area. The river in the study site also supports a variety of other users and purposes, including local and farming use (i.e., irrigation source), subsistence fishing, religious use (i.e., temple sanctuaries), and tourism (i.e., rafting). Illegal sand-mining operations also occur on this stretch of the Cauvery (S. Bower, personal observation). Water temperatures during the rapid assessment averaged 27 ± 2˚C.

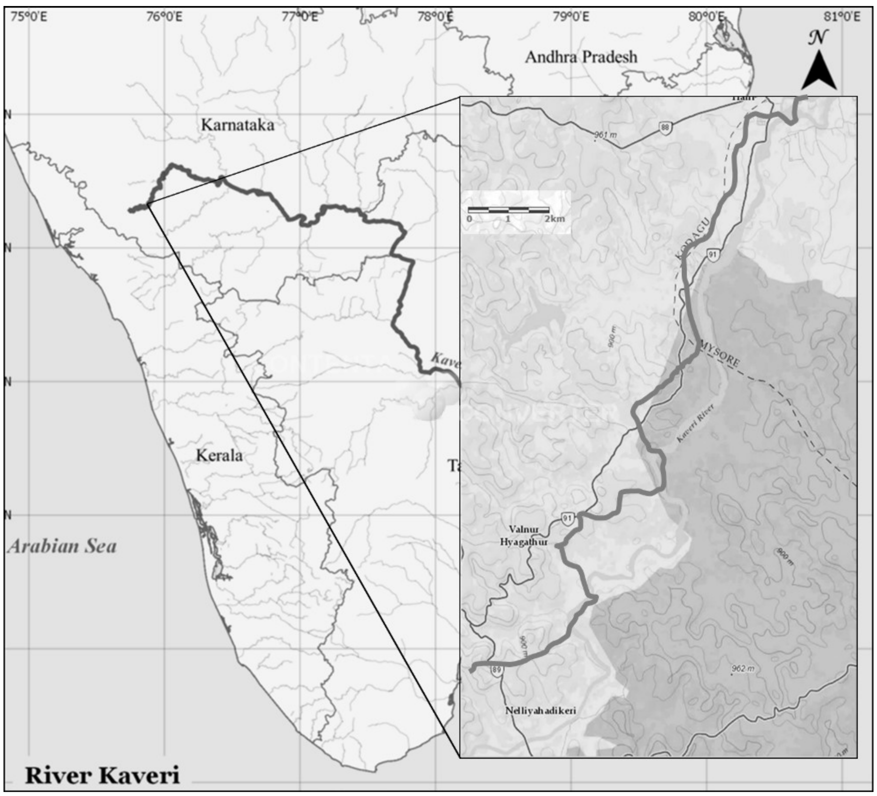

Figure 4.1 Location of the Cauvery River in India and the rapid assessment sampling area in Valnur, Coorg (inset).

Angling Practices

Angling and sampling was conducted over the course of three days along a 20-km stretch of the Cauvery by two assessment teams, each consisting of between three to six anglers and an individual responsible for processing samples and recording data. Rather than simulating fisheries, local anglers and river managers were engaged to ensure that C&R practices studied reflected actual practices used for blue-finned mahseer (Cooke et al. 2013; Figure 4.2). To account for differences in angler expertise (anglers varied in experience from novice anglers with little fishing experience overall to expert anglers with decades of fishing experience in the study area), each angler spent time collecting fish for both groups over the course of the rapid assessment.

Figure 4.2 Blue-finned mahseer (*Tor* sp.) during analysis. Photo credit: Steve Lockett

All anglers used light- to mid-weight spinning gear and adopted a variety of terminal tackle (hereafter collectively referred to as ‘lure types’), all of which are commonly employed in the recreational fishery, including: spoons, spinners, plugs, soft baits, and a traditional flour-based dough bait locally referred to as 'ragi' (see Figure 4.3). Ragi recipes use a variety of spices and flavours, but are universally fashioned into a balled shape around a single barbed or barbless hook. Pellet floats were also used to target mahseer, a technique less commonly employed in the area. Angling took place from shore, from a dinghy and from a coracle (a traditional round-bottomed boat; Figure 4.3).

Figure 4.3. A) Ragi ball affixed to a single, barbed hook; a traditional bait used in the mahseer recreational fisheries of south India. B) Volunteer anglers fish from a coracle, a traditional round-bottomed boat used for fishing activities in south India. Photo credits: Shannon Bower

Rapid Assessment Protocols

Over the course of the rapid assessment, 49 blue-finned mahseer were angled and processed. Prior to angling, the lure type, number of hooks, and hook type (barbed or barbless) were recorded. Processing began by recording the time taken to land the fish (angling time in sec), beginning from the initial setting of the hook by the angler and terminating at landing. Once landed, the anatomical hooking location for each fish was recorded, and each fish was measured (total length in mm; TL). Fish were scored for the presence of injury using a standardized objective scoring system, where a score of 0 indicated no discernible injury; a score of 1 indicated a minor injury such as minor tearing of tissue (i.e., < 5mm in length, including any visible tissue tear or abrasion resulting from hooking); a score of 2 indicated moderate injury such as the presence of bleeding, bruising or a tissue tear > 5 mm in length; and a score of 3 indicated major injury, such as ocular or gill damage with significant pulsatile bleeding (as per Gutowsky et al. 2011). A standardized scoring system was also applied to describe the ease of hook removal, where a score of 0 referred to a hook that was removed easily and immediately (i.e., in < 10 sec); a score of 1 referred to a hook that required between 10 and 20 sec to remove; and a score of 2 was assigned when hooks required > 20 sec to remove (a time-based variation on hook removal scores used in Cooke et al. 2001). To standardize scoring methods, only those fish scored for injury and hook removal by the assessment teams were included in analysis for these variables. Landed fish processed for non-score variables (length, lure type, hook type, angling time) by team members without *a priori* training in scoring standards were not included in analysis of scored variables (injury, ease of hook removal). The cumulative amount of air exposure time (sec) accrued during handling was recorded by all participants.

A 'whole body' stress response in fish can take the form of immediate (e.g., inhibition of reflex behaviours) and/or delayed responses, such as decreased reproductive outputs or growth (Pankhurst and Van DerKraak 1997). Immediate reflex responses may be measured during a rapid assessment using reflex action mortality predictors, indicators developed by Davis (2010). The use of indicators to measure reflex responses as proxies for physiological stress and as predictors for post-release mortality and behavioural impairment have been used in a variety of teleost fish studies (e.g., *Oncorhynchus kisutch* Walbaum, Raby et al. 2012; *Albula vulpes* Linnaeus, Brownscombe et al. 2013). With the fish submerged, reflex impairment indicators were measured prior to release. Four reflex indicators were used in this rapid assessment, including: 'tail grab' (fish exhibits burst swimming reflex when grabbed by the tail); 'body flex' (fish flexes torso when held along the dorsoventral axis); 'head complex' (fish exhibits steady operculum beats during handling); and, 'equilibrium' (fish rights itself within three seconds after being placed upside-down in water; Davis 2010). Binary reflex impairment scores of 0 (reflex present) or 1 (reflex absent) were assigned to each indicator measurement, resulting in a total score ranging from 0-4. These individual reflex impairment indicator scores were then combined to produce a proportional impairment score ranging from 0-1 for each fish, where 0 indicated no overall impairment and 1 indicated total impairment.

Blood-Sampling

In addition to measuring reflex responses, non-lethal blood samples were obtained from a subset of fish (N=36) to quantify the physiological stress response of mahseer to C&R angling. These responses may be measured in a rapid assessment by obtaining a non-lethal blood sample from the caudal vasculature (Barton et al. 2002) and processed quickly in the field using point-of-care devices and techniques validated on fish and other species (as reviewed by Stoot et al. 2014). Prior to sampling, these fish were subject to the same measurements as described above. Following these measurements, fish in the blood-sampled subgroup were sampled immediately (i.e., in < 30 sec; as per Meka and McCormick 2005).

Non-lethal blood samples were obtained by temporarily inverting fish in the water column while <1 ml of blood was drawn from the caudal vasculature with a 22G needle (BD Vacutainer Multi-sample Needles and 4.0 ml lithium heparin collection tubes, 75 USP, Becton, Dickson and Company (BD), New Jersey, USA). Blood was analyzed onsite immediately after withdrawal for blood lactate (mmol/L, Lactate Pro LT-1710, Arkray Inc., Kyoto, Japan), glucose (mmol/ L, Accu-Chek Compact Plus, Roche Diagnostics, Basel, Switzerland) and pH (HI-99161, Hanna Instruments, Woonsocket, Rhode Island, USA). Fish that were blood sampled were released immediately after sampling was completed. All experimental manipulations performed during this study were conducted in accordance with Canadian Council of Animal Care regulations under permit number B13-02 (file # 100105).

Statistical Analyses

To determine whether angling variables such as lure type, angling time, air exposure and difficulty of hook removal influenced differences in injury score (mortality rate was not included as no cases of mortality were observed), Chi-Square (lure type, difficulty of hook removal) and Kruskal-Wallis tests (angling time, air exposure time) were employed. Tukey's HSD tests were applied as post hoc testing for all Kruskal-Wallis tests.

To evaluate stress response in blood-sampled mahseer, general linear models were applied to measure the relationship between blood values (glucose, lactate and pH) and angling variables (angling time, air exposure). To normalize residuals in the model examining angling variable contributions to blood glucose values, blood glucose values were log-transformed but predictor variables were not (as recommended in Zuur et al. 2009). Contributions from uncontrolled independent variables (i.e., water temperature, ˚C; TL, mm), were accounted for by including these variables in analysis. Models were chosen based on a combination of parsimony (i.e., fewest variables explaining the most variation) and minimum Akaike Information Criterion (AIC) value.

To compare reflex impairment responses among mahseer subject to different angling times, air exposure times, lure type and injury score Chi-Square analyses (lure type, injury score) and Kruskal-Wallis analyses (angling time, air exposure time) were performed. Reflex impairment scores were treated as objective measurements during analysis (reflex impairment scores were converted to ordinal variables; 0.0, 0.25, 0.5, 0.75, 1), a common assumption in studies using reflex impairment scoring (see Raby et al. 2012; Brownscombe et al. 2013; Nguyen et al. 2014 for examples). However, the low numbers of non-zero reflex impairment scores prevented formal statistical analysis by individual score category. Thus, non-zero reflex impairment scores were binned into a single category and the contributions of angling time, air exposure, lure type and injury score to non-zero reflex impairment scores were measured.

The dataset's compliance with assumptions of homogeneity of variance and normality of distribution were assessed using Levene and Shapiro-Wilk tests on each variable prior to analysis. Variables found to meet assumptions were treated with general linear models, while the remainder were subject to the non-parametric analyses described above. Unless otherwise noted, all data are presented as mean ± standard error. All analyses were conducted using R (version 3.1.0, © 2014, The R Foundation for Statistical Computing, Vienna, Austria).

Results

Injury and Mortality

Of the 44 angled blue-finned mahseer assessed for hooking location, most (91%) were hooked in the mouth, specifically in the corner of the mouth (N=16), lower jaw (N=12), or upper jaw (N=12). Four fish (9%) were foul-hooked, and each instance of foul-hooking was also categorized as a minor, moderate or major injury, according to the degree of resulting tissue damage. Of the 39 fish assessed for injury, 23 were classified as having minor (N=18, including two instances of foul-hooking) or moderate (N=5, including one instance of foul-hooking) injury, and one fish exhibited major injury in the form of a loss of perfusion to fins and damage to the 2nd gill arch after being foul-hooked in the gills.

Increases in injury score were not associated with gear-related variables such as lure type (χ^2=6.49, df=8, p=0.59), or hooking location (χ^2=5.60, df=8, p=0.69). Increased difficulty in hook removal (χ^2=5.66, df=6, p=0.07), extended angling times (χ^2=1.13, df=2, p=0.57), or extended air exposures (χ^2=2.34, df=2, p=0.31) also did not significantly increase injury score. Finally, there were no observed instances of mortality during this study, though one highly impaired and injured fish (see above) was not expected to survive over the short term.

Blood Chemistry

Mean length of mahseer angled for the rapid assessment was 458 ± 20 mm TL (N=49; range 200 – 700mm TL), while fish in the blood-sampled subset (N=36) averaged 443 ± 24 mm TL. Mean values for blood glucose, lactate and pH in this sampled subset were 2.5 ± 0.2 mmol/L, 5.7 ± 0.4 mmol/L and 7.30 ± 0.16 respectively. GLM models identified which angling variables (angling time, air exposure time, TL, and water temperature) contributed most to variability in physiological parameters. In the model analyzing factors contributing to blood lactate values, the lowest AIC value occurred when all independent variables (angling variables above) were included in the model. However, when all independent variables but angling time (the only statistically significant predictor) were removed from the model, AIC value remained low and the adjusted R-squared value remained stable (Adj. R^2 for full model=0.47, Adj. R^2 for reduced model=0.46). As such, the latter model was chosen on the basis of parsimony and revealed that elevated blood lactate values in mahseer were significantly, though weakly, correlated with longer angling times (Adj. R^2=0.46, F=31.37, df=34, p<0.001). The lowest AIC values in the model analyzing angler variable contributions to log-transformed blood glucose occurred when all variables were retained. This model revealed that lengthened air exposure times (t=2.73, p=0.01), longer angling times (t=3.39, p=0.002), and shorter fish lengths (t=-4.4, p<0.001) all correlated with increased blood glucose values (Adj. R^2=0.42, F=5.13, df=28, p= 0.001). Finally, angling time was also identified as being the variable contributing most to changes in blood pH of sampled mahseer, with the lowest AIC value and most parsimonious model occurring when all variables but angling time were removed. Extended angling times were correlated with significant decreases in mahseer blood pH (Adj. R^2=0.55, F=7.94, df=33, p<0.001).

Reflex Impairment

Mean reflex impairment score for the total number of fish measured for reflex impairment (N=49) was 0.20. Sixteen mahseer (33%) tested positive for impairment for at least one of the four reflex impairment indicators tested. Seven of these 16 mahseer scored 0.25, indicating impairment of a single reflex behaviour. Four mahseer scored 0.50, indicating impairment of two reflex behaviours, and four mahseer scored 0.75, indicating impairment of three reflex behaviours. Lastly, one mahseer scored 1.00, indicating that all four reflexes were impaired. Among the indicators measured, equilibrium, and tail grab were most commonly impaired, followed by body flex, and head complex (Figure 4.4).

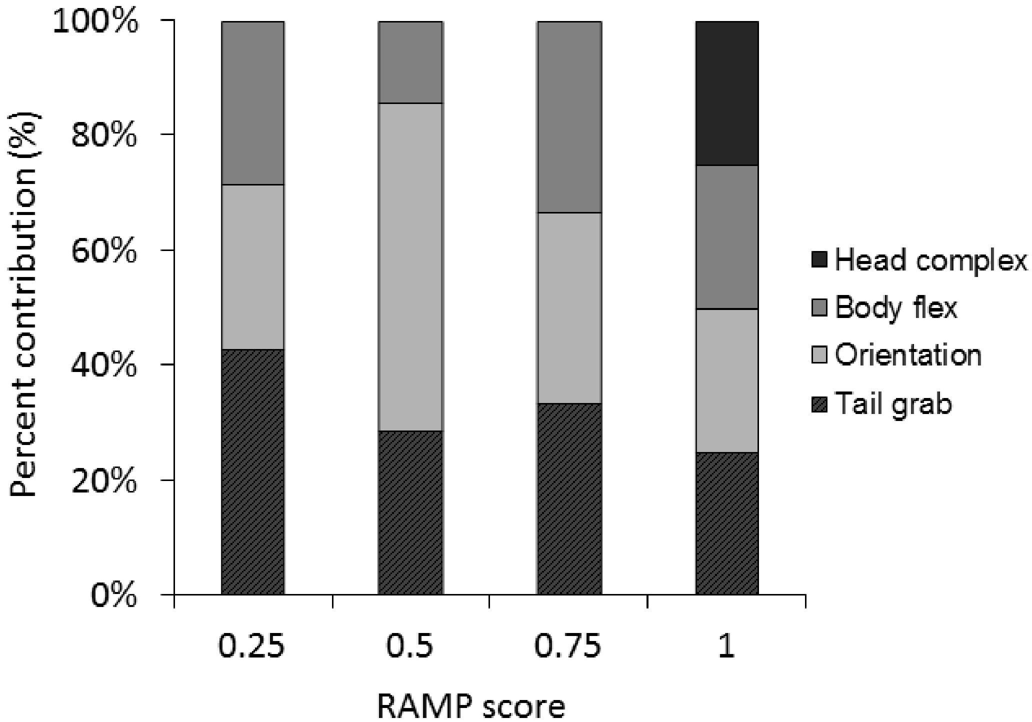

Figure 4.4 Proportional contributions of individual indicators to reflex impairment score (0, 0.25, 0.5, 0.75, 1).

Air exposure, angling time, lure type and injury score were included in analyses of mahseer RAMP score. Longer air exposure times were significantly more likely to result in non-zero RAMP scores (χ^2=5.55, df=1, p=0.02), as were longer angling times (χ^2=4.02, df=1, p=0.045). Of the different lure types used (pellet floats, plugs, ragi, soft plastics, spinners and spoons), spinners caught the most mahseer over the study period (25 of 49 fish were angled using spinners). However, I did not track lure-specific catch-per-unit-effort so it is unclear which lure type was most effective. Possibly due to the dominance of captures by spinners, no one lure type was associated with a significant increase in RAMP score, suggesting that reflex impairment was not related to lure type in this study (χ^2=4.11, df=6, p=0.53). Nor were injured fish more likely to demonstrate reflex impairment: among mahseer angled during the rapid assessment, there was no evidence of a significant relationship between injury scores (1, 2, 3) and non-zero RAMP scores (χ^2=5.66, df=3, p=0.12).

Discussion

Overall, injuries were found to be minor in nature and mortality was negligible in the mahseer rapid assessment. A high rate of minor injury to mahseer was observed (46%), but this was likely due to the conservative standards employed in the assessment of injury. It is worth noting that it is impossible to capture a fish by hook without causing some level of injury; an unavoidable function of hook and tissue interaction (Cooke and Sneddon 2007). Measurements of injury were categorized using conservative standards by including any visible tissue damage, including hook puncture sites, as a minor injury and by considering a tissue tear > 5 mm as a moderate injury. This standard was deemed appropriately risk averse due to the endangered status of mahseer. Given the lack of significant association between injury and angling variables such as gear type, this standard was likely responsible for the high rate of minor (23 of 39 fish assessed for injury) and moderate (five of 39 fish assessed) injury recorded during the rapid assessment. The rate of foul-hooking (9%) may also be a result of the use of treble hooked lures in targeting blue-finned mahseer (commonly considered to be an aggressive striking fish). These lures are commonly employed in the study area, but to date less frequently used elsewhere in south India (D. Plummer, Cauvery River angling guide, personal communication). Despite this relatively high rate of minor injury (60%), 91% of these injuries occurred at the hook site in the mouth. Throughout the study, only one fish was considered likely to die, but no cases of mortality were observed during the study period. Additional mortality can occur after release (i.e., delayed mortality) but fish were generally vigorous at time of release with little reflex impairment (see below) suggesting mortality was unlikely.

Analysis of blood chemistry in angled blue-finned mahseer revealed that longer angling times correlated with increases in blood lactate and glucose, and decreases in blood pH, while longer air exposure times and smaller fish size were found to correlate with higher blood glucose values. The relationship between angling time and key stress markers has been documented in many species, including great barracuda (*Sphyraena barracuda* Edwards; O'Toole et al. 2010) and bonefish (*A. vulpes* Linnaeus; Suski et al. 2007). As with angling time, the relationship between longer air exposure times and increases in blood glucose has also been noted in other popular sport fish, such as largemouth bass (*M. salmoides* Lacépède; White et al. 2008) and northern pike (*Esox Lucius* Linnaeus; Arlinghaus et al. 2009). The negative relationship between air exposure and fish length in this study, however, is contrary to typical findings that describe larger-bodied fish as more likely to exhibit higher stress responses (see Meka and McCormick, 2005). Meka and McCormick (2005) postulated that fish maintaining a higher weight/length ratio may exhibit increased stress response as a result of experiencing more anaerobic exercise (than fish maintaining a lower weight/length ratio) during a stressor of equal duration and intensity. No trophy-sized fish (blue-finned mahseer can attain masses that exceed 50kg in this region; Pinder et al. In Press) were landed during the rapid assessment, however, and as mahseer weight was not measured it was not possible to determine whether this hypothesis applies to blue-finned mahseer.

The potential impacts of species-specific stress responses are also important to consider. For example, the amount of variability in blood lactate, glucose and pH measurements explained by the predictors was low, suggesting that these correlations may be weak in this species. Weak correlations may also be a result of species-specific physiological traits robust to such stressors. Nonetheless, I did observe that quickly angled mahseer (i.e., angled and sampled in < 1 min, N=9) had levels of lactate that averaged 3.9 ± 0.2 mmol/l which is presumably indicative of near-baseline values for this species (Romero 2004). My minimum values for lactate were 1.4 ± 0.2 mmol/L with a maximum of 11.6 ± 0.2 mmol/L. Given the potamodromous ecology of mahseer, further study to explore the role of lactate metabolism in mahseer recovery from angling is warranted.

Exploratory analysis of RAMP scores demonstrated that rates of mahseer reflex impairment were relatively low, with the 40 of 49 fish exhibiting no impairment (N=33) or impairment of a single indicator behaviour (N=7). Burst swimming and equilibrium were the most likely to be impaired, followed by loss of torso flexion and irregular operculum beats. While other studies employing RAMP have also found that the burst swimming reflex is most likely to be impaired (e.g., see Raby et al. 2012; Brownscombe et al. 2013), these studies also found that loss of torso flexion was the second most frequently impaired reflex. During my rapid assessment, it was noted that body flex in mahseer is less evident than in other species and therefore its presence or absence was less easily visible. Anglers using RAMP to assess the status of landed fish prior to release, or future studies incorporating measurements of RAMP to study mahseer, should consider prioritizing indicators other than body flex.

Longer angling and air exposure times were the variables most likely to contribute to non-zero (impaired) RAMP scores. The rate of minor impairment (14%) in this study further suggests that negative reflex response to these angling stressors is not uncommon in mahseer. Both the contributions of angling variables and this evidence of reflex impairment suggest that further research into the occurrence of sub-lethal effects in mahseer may be advisable.

Conclusions from Rapid Assessment and Recommended Best Practices

The rapid assessment findings suggest mahseer are robust to C&R, but also provide data to support the development of best angling practices designed to reduce unnecessarily long angling times and air exposures. While angling times for larger-bodied fish are likely to be longer than for smaller fish, anglers should opt for gear choices appropriate to their target species as inappropriate gear choices can result in extended angling times (Meka and McCormick 2005) and avoid unnecessary delay in landing hooked fish. Handling time may be reduced by using fewer hooks (*i.e*, single hooks rather than treble hooks) and/or barbless hooks, which may reduce the time needed for hook removal (Cooke *et al*. 2001). Anglers should also attempt to reduce the amount of time landed fish are subjected to air exposure, particularly in higher water temperatures (Gingerich et al. 2007). In this study, mahseer demonstrated increased blood glucose after air exposures greater than 30 seconds in mean water temperatures of 27 ± 2˚C, which could be considered a conservative maximum for cumulative exposure time in similar conditions.

Future research recommendations include quantifying the physiological stress responses of larger-bodied fish (i.e., trophy mahseer) and identifying sub-lethal impacts resulting from angling, particularly those relevant to mahseer natural history (which is understudied in most *Tor* spp.; Nautiyal 2014). Fish considered to be of trophy size were not targeted or captured in this study. Such mahseer are known to be subject to fight times often exceeding one hour (D. Plummer, Cauvery River angling guide, personal communication) and may therefore be more susceptible to delayed recovery and stress-induced mortality. The physiological challenges posed by migration behaviours may increase the likelihood sub-lethal impacts of recreational angling on mahseer at certain times of year (i.e.*,* migratory periods) or in differing environmental conditions (i.e., different water temperatures). It should be noted that mahseer are not typically targeted by C&R anglers during monsoon season (approximately May-October); however, migration phases may extend beyond monsoon season according to habitat type/life stage (e.g., *T. putitora* Hamilton is believed to migrate at different times according to age class; Nautiyal 2014). Moreover, information on population size and demographics/life-history characteristics (e.g., age at maturation, natural mortality rates) is needed to understand the level of C&R-induced mortality than can be considered sustainable – information that is typically absent for endangered species targeted by recreational C&R anglers (Cooke et al. 2014).

Chapter 5. Sub-lethal responses of mahseer (*Tor khudree*) to catch-and-release recreational angling

Abstract

Fishes exhibit a range of biological responses to the process of catch-and-release recreational angling. In the last decade, research has begun to consider how such fisheries interactions alter the behaviour (e.g., movement, feeding activity, reproduction) of fish upon release. In this study, I assessed reflex impairment and then affixed radio-telemetry transmitters to 34 blue-finned mahseer (*Tor khudree*) angled on the Cauvery River, Karnataka, India, between February and May of 2015, and tracked their subsequent movements over three time scales: 90 min post-release, hourly over a 24-hr period, and daily from the release date to the end of the study. When testing reflex impairment, mahseer were more likely to first lose response to tail grab, followed by loss of orientation, then developed irregular operculum beats. Neither reflex impairment nor time taken for fish to swim away from the release site varied reliably with air exposure or handling time. Similarly, movement rates of mahseer were consistent across tagging periods. However, trends did indicate that larger fish subject to longer angling and handling times took longer to leave the release site, moved less during the initial release period, and moved less over a 24-hr cycle. I recommend that anglers view the presence of irregular operculum beats as an indicator of extreme impairment in mahseer. I also recommend further study of size- and age-based differences in mahseer behaviour, including specific research on responses of trophy-sized mahseer to catch-and-release angling. My work contributes to the understanding of sublethal behavioural consequences of catch-and-release while generating some of the first information to guide development of best practice guidelines for those catching and releasing mahseer.

Introduction

Many anglers around the world practice catch-and-release (C&R), as an estimated two-thirds of ~47 billion fish caught during recreational fishing activities per year are released back into the water (Cooke and Cowx 2004). Defined as 'the act of returning a fish to the water after capture, presumably unharmed' (Arlinghaus et al. 2007), the success of C&R as a conservation strategy is highly dependent on the degree of physiological disturbance experienced by fishes during capture and handling. The level of physiological disturbance can range from mild physiological stress from which fish recover to severe physiological impairment which leads to post-release mortality (see reviews by Cooke and Suski 2005; Arlinghaus et al. 2007). 'Sub-lethal consequences' refers to outcomes experienced by fishes that, while not resulting in death, do result in physiological or behavioural changes over the short to long-term (Cooke et al. 2002). These consequences can include increased susceptibility to post-release predation (a lethal outcome) through alterations in movement, changes in migration, feeding, or parental care patterns, and changes in habitat associations (Thorstad et al. 2003; Hanson et al. 2007; Suski et al. 2007; Klefoth et al. 2008). There is growing recognition that behavioural outcomes for animals that interact with humans can be used as objective assessments of animal condition needed to understand consequences of human activities on wildlife (Sutherland 1998; Caro 1999). Behavioural outcomes can also be used to identify opportunities to improve welfare of animals (Swaisgood 2007).

Notwithstanding some inherent drawbacks to the approach, including challenges establishing control groups and accounting for additional stress and mortality through the tagging process, biotelemetry is an ideal method for examining sub-lethal consequences of C&R on released fishes (Donaldson et al. 2008). Using radio telemetry, the movement of released fishes in various conditions can be remotely tracked without the need for further contact or handling. By comparing movement rates among groups (if a control is established; e.g., Lennox et al. 2015) or among tagging dates (e.g., Klefoth et al. 2008), the degree of increase or decrease in movement according to key angling variables, such as extended angling and air exposure times, can be measured and inferences made about sub-lethal effects of C&R. Individual sub-lethal effects may result in population-level disturbances, depending on parameters such as the amount of angling pressure and population size (Skomal, 2007), though drawing tangible linkages to population-level cascades is challenging due to the compounding factors influencing fish survival and fitness over time (Cooke et al. 2013).

The mahseer recreational fishery in India was first documented as early as the 12th century (Nautiyal 2014). Indian mahseer populations consist of seven valid species, four of which are endangered in their native ranges, including the two most popular game species *Tor khudree* (blue-finned mahseer; Raghavan 2011) and *Tor putitora* (golden mahseer; Jha and Rayamajhi 2010). Declines in the size and abundance of these target species were noted by anglers during the 1970s, leading to the formation of angling conservation groups and coalitions (e.g., Wildlife Association of South India [WASI], Coorg Wildlife Society [CWS]) who established angling camps and began collecting catch data (Pinder and Raghavan, 2013). Such groups promoted C&R fishing and hired local fishers to act as guides and guards of river reaches they managed (Gupta et al. 2015). Despite the cultural and recreational importance of these species, however, data deficiencies surrounding basic biology and ecology of mahseer are widespread (Raghavan et al. 2011; Pinder and Raghavan 2013) and many questions about the suitability of the species for C&R remain.

A previous study examining the immediate responses of blue-finned mahseer to C&R indicated that while post-release mortality was likely to be low, extended angling times resulted in significant increases in blood lactate, and air exposure led to increased reflex impairment (Bower et al. 2016). These results suggest that C&R activities may lead to sub-lethal consequences in blue-finned mahseer. I used radio telemetry to identify the presence of any sub-lethal consequences arising as a result of C&R activities in the mahseer recreational fishery of the Cauvery River, in Karnataka, India. My objective for this study therefore, was to use changes in post-release movement rates as a proxy for sub-lethal disturbances to determine whether differences in key angling variables (angling time, handling time, air exposure) resulted in significant changes to post-release movement rates in *T. khudree* because of C&R. To my knowledge, this was the first freshwater biotelemetry study conducted in India.

Methods

Study Site

The Cauvery River runs 800 km from its headwaters in Talakaveri to the Bay of Bengal, through the Indian states of Karnataka, Tamil Nadu, Kerala, and Puducherry. The depth of the river fluctuates strongly according to monsoon period, with the shallowest depths and warmest temperatures closest to the study site typically occurring through the months of March to June (mean temperature = 28 ºC) and the coolest temperatures and deepest water occurring during monsoon months from July to September (mean temperature = 24 ºC; Central Water Commission 2012). This study took place in Valnur, Coorg (Karnataka, India) along a 4 km stretch of the Cauvery River controlled by the Coorg Wildlife Society (CWS; Figure 5.1) from

February 19 – April 24, 2015. Mean water temperatures during this study were 27 ± 2 ºC (range = 22 ºC – 30 ºC).

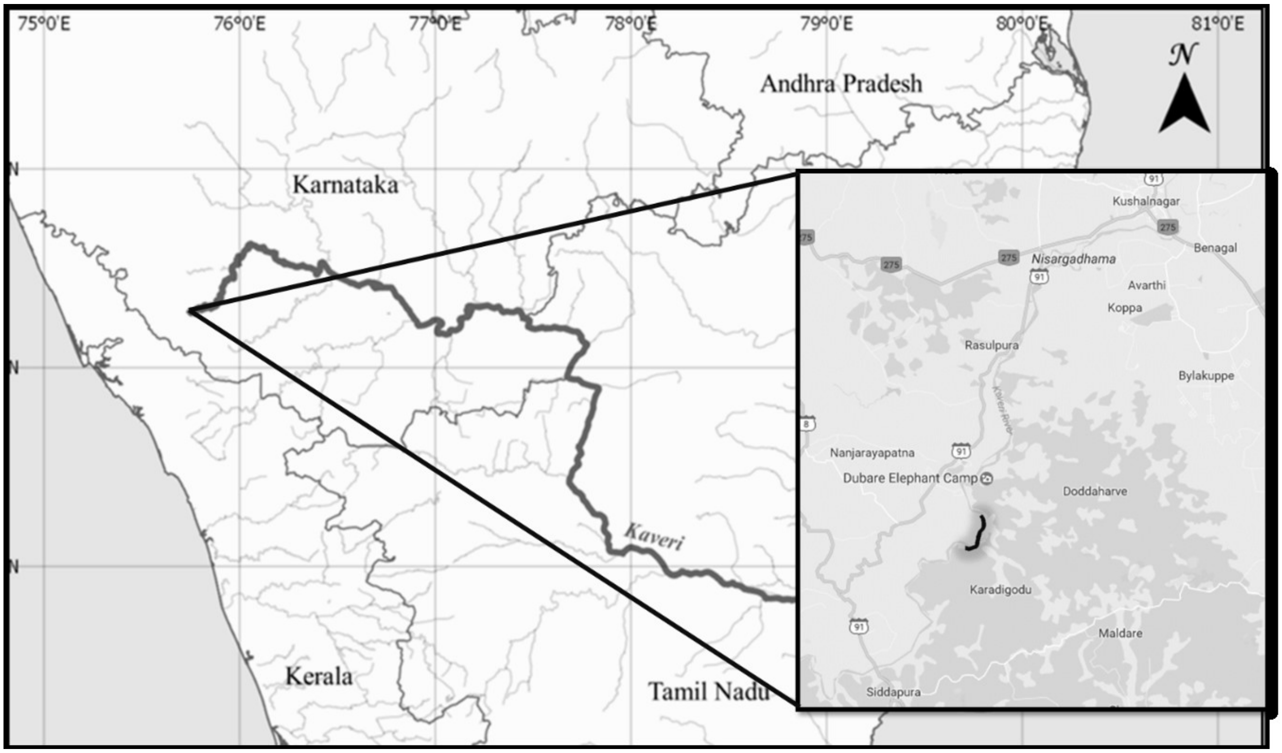

Figure 5.1 Map indicating the location of the Cauvery River in South India, with the location of the field site in Valnur, Coorg emphasized in black (inset).

Angling and Tagging Procedures

Blue-finned mahseer were angled throughout the study period using mid- and heavy-weight conventional rods and reels. Mahseer were caught using lures such as plastic shads and crankbaits and ragi (a flour paste bait mixture), both commonly used methods in the area. Angling time was recorded as the amount of time (s) taken from hook set to the removal of fish from the water. Air exposure time was recorded as the amount of time (s) taken from the removal of fish from the water to the placement of fish in the trough for tagging. Handling time was recorded as the amount of time (s) taken to process the fish from trough placement to release, including hook removal, the tagging process, and the assessment of reflex impairment (Davis 2010) immediately prior to and after tagging. Three reflex indicators were measured: ‘tail grab’, the presence of a burst swim response to being gripped by the caudal peduncle; ‘operculum beats’, the presence of steady (as opposed to irregular) operculum beats; and, ‘orientation’, the presence of the ability for the fish to right itself when placed upside down in water. A commonly used fourth indicator, ‘body flex’, the presence of torso flexion in the fish when gripped along the dorsoventral axis, was not used in this study as prior research on this species using reflex impairment assessment noted the overall lack of body flex responses in the species (see Bower et al. 2016).

Immediately after the first reflex assessment (reflex 1), landed mahseer were measured for total length (TL, mm), and injury score, followed by the tagging procedure. While submerged in a water-filled trough with head covered, fish were affixed with one of two radio tags, depending on fish size (Advanced Telemetry Systems Inc., Seattle, USA, models F1970 [4.3 g] and F1930 [2.4 g]). Tags were placed dorsally, to the rear of the dorsal fin such that the antennae would not impede water flow. Fixation of the tags required using two hollow 1.5 in, 18-gauge needles to pierce dorsal musculature. Coated 0.8 mm wires attached to the radio tag were fed through the hollow needles and stoppered on the opposite side (as in Lennox et al. 2015). After tagging, mahseer were measured for a second reflex impairment score (reflex 2) and released. On release, the time taken for each fish to move 1m, 5m, and 10m (referred to hereafter as ‘swim away times’) from the release site was recorded (s).

Tracking Procedures

All fish were tracked from a walking trail immediately adjacent to the river using a handheld receiver (Communications Specialists, Inc., Orange, USA, model R-1000) and short, three-element handheld antenna. Fish positions were determined using successive gain reductions, and once identified, positions were recorded using a handheld GPS unit (Garmin Ltd., Schaffhausen, Switzerland, model GPSMAP 60cx) to within ±5m. This technique resulted in an established river position along the Y-axis (river length), but not along X- or Z- axes (river width or depth). To facilitate the comparison of distance measurements, positions were recorded using the Universal Transverse Mercator (UTM) system. These positions were later translated into standard latitudinal and longitudinal coordinates for mapping fish movements.

Bettoli and Osborne (1998) noted that mortality estimates in telemetry studies typically use stationary tags as a proxy for mortality. In this study, all tags that became stationary were attached to fish that had been released in excellent body condition and demonstrated movement consistent with live fish prior to cessation of movement, suggesting stationary positions were caused by tag loss and not mortality (see Yergey et al. 2012). On occasions where mahseer demonstrated no movement after four days, the fish were tracked multiple times daily to confirm that a stationary position was indeed occurring. If mahseer continued to demonstrate zero movement for three additional days (a total of seven days), the tag was considered lost and data was not analyzed from the initial point of movement cessation onwards. As such, tag loss did not interfere with post-release tracking or diel movement studies as no fish lost tags during the immediate post-release period, and fish demonstrating a permanently stationary position indicating tag loss were not included in diel movement studies.

Post-Release Tracking

Immediately after release, mahseer were tracked over a 90-min period, with positions established every five min. If released mahseer established a holding location prior to the end of the 90-min tracking period, tracking continued until the end of the 90-min period (19 positions, including the initial release site). If released mahseer continued to move actively throughout the 90-min tracking period, tracking continued until a holding period was established and confirmed (i.e., at least three measurements in the same location). Post-release tracking periods vary in the literature, e.g., up to 60 min to observe post-release predation in *Albula vulpes* (Danylchuk et al. 2007). In my study, post-release tracking periods were constrained by the time of day. On seven occasions, tracking during the initial release period was shorter than 90 min due to the arrival of nightfall on the river (1900 hrs), which posed a safety hazard as elephant traffic was very common in the study reach at nightfall. However, on all but one occasion, fish tracked during twilight had established a holding period prior to cessation of tracking.

Diel Movement Tracking

Mahseer were tracked over a full 24 hr period on two occasions. Fish were located each hour over the course of a 24-hr period, however, due to the presence of elephant traffic I was forced to cease tracking on three occasions and resume coverage of the 24-hr period on a subsequent date when sufficient personnel were available to assist. The difficulty of tracking the river reach safely at night meant it was not possible to track each fish every hour (though positions were obtained for each fish throughout the 24-hr period, for example, for some fish a data point may be missing for 0400hrs, but positions for 0300 hrs and 0500 hrs were recorded). As a result, the average number of data points per fish in the diel movement portion of the study was 19 (range = 7 hrs – 23). As the river reach studied was too long to enable the tracking all the study fish each hour, I opted to separate tracking sessions into two river reaches. The first reach was tracked on March 19th, March 29th, and April 4th, 2015. The second reach was tracked on April 16th, April 17th, and April 23rd, 2015.

Daily Position Tracking

All released mahseer were tracked daily along the entire study reach beginning from the date they were caught (tagging date) and continuing until April 21th, 2015. Of a total 60 possible tracking days, the average tracking period was 32 tracking days (range = 1 – 57 tracking days). Timing of daily tracking sessions varied such that tracking occurred throughout the daylight period (beginning of daylight at 0637 hrs until end of civil twilight at 1900 hrs).

Management and Statistical Analyses

Due to the non-normal distributions commonly associated with small sample size, non-parametric analyses were preferentially applied, however all variables were examined for homogeneity of variance and/or residual distribution prior to testing using Shapiro-Wilks test, Levene's test, or residual plots. Any variables displaying non-normal distribution were then transformed if parametric testing was indicated.

Angling Variable Analyses

Reflex scores 1 and 2 were compared using an Exact McNemar test for paired nominal data to identify any significant differences between the two scores, as significant differences would suggest that the tagging process led to significantly more impairment than the angling process alone. To perform this test, reflex scores were reduced to a binary frequency (where 0 indicated 'unimpaired' and 1 indicated 'impaired'). I then used generalized linear regression models (logistic regression) to examine any significant contributions of angling variables (angling time, log air exposure) to the reduced reflex 1 score and handling time to the reduced reflex 2 score when controlling for TL. General linear models were used to determine whether increases in the angling variables (angling time, handling time, log air exposure) resulted in significant increases or decreases in release variables (all swim away times) when controlling for TL. Generalized linear models were also used to evaluate whether the presence or absence of impairment (using reflex 2 scores) resulted in significant increases or decreases in swim away times when controlling for TL.

Tracking Variable Analyses

Total distance travelled (m) by individual fish during all tracking periods was calculated as a sum of the distances travelled from previous coordinates to account for fish movement in upstream and downstream directions (hereafter referred to as 'total distance'). For example, a fish that travelled upstream by 50 m after release, before travelling downstream by a 100 m and then returning to the original release site would register a total travel distance of 200 m despite the net movement over the tracking period being 0 m. Similarly, a ratio measurement of total distance travelled (m) by the amount of time spent tracking (min; hereafter referred to as 'ratio distance') was developed to account for differences in the number of tracking measurements taken.

Post-release tracking variables were measured as: the distance travelled (m) over the first five min post-release, the distance travelled (m) over the first ten min post-release, ratio distance (m/min), and the longest distance travelled (m) between tracking measurements over the post-release period. Angling variables (angling time, air exposure time, handling time) and reflex scores were used as independent variables in general and generalized linear models respectively to identify any significant contributions to post-release tracking variables.

I generated descriptive statistics for the diel movement studies to identify time-based patterns of movement in *T. khudree*. Diel movement variables included the distance travelled per hr (m) and the longest distance covered between measurements per session (m). A general linear model was applied to determine the effect of tag days (the number of days since tagging and release) on mahseer movements as measured by distance travelled per hr (m) and the longest distance covered between measurements per session (m). All data are presented as mean ± standard deviation unless otherwise specified. All analyses were performed in R (version 3.3.3, © 2016, The R Foundation for Statistical Computing, Vienna, Austria).

The daily position of mahseer did not provide any inference regarding the total amount of mahseer movement pertaining to C&R. Tracking released fish daily allowed us the opportunity to develop a baseline expectation of mahseer location for post-release and diel tracking periods. Excepting two events, no mahseer were found outside of the reach in which they were caught and released throughout the duration of the study. As such, no further analysis on positional data relating to C&R was performed for the daily position dataset.

Results

Blue-finned mahseer angled during this study (N=34) ranged from 200 to 1050 mm TL (mean = 597 mm TL, SD= 189 mm). Of these, 15 mahseer were caught using lures such as plastic shads and crankbaits, and the remainder were caught using ragi (a flour paste bait mixture). Of the total number of fish caught and tagged (N = 34), four fish demonstrated stationary positions and were assumed to have shed their tags and tracking was discontinued as per the above protocol. All attempts to retrieve lost tags were unsuccessful. Additionally, no tagged fish were recaptured during the study period.

Angling Variables

Angling times ranged from 104 s to 1020 s, with a mean of 362 ± 40 s. Handling times varied over a similar duration, ranging from 170 s to 1054 s (mean = 539 ± 40 s), while air exposure ranged from 0 s to 149 s (mean = 30 ± 6 s). Angling time and handling time demonstrated a stronger linear relationship with 1 m and 5 m swim away times than air exposure, however logistic regression analysis indicated that neither increased angling time, handling time, nor log air exposure resulted in reflex impairment when controlling for TL (angling time, $z = 0.76$, df = 32, p = 0.45; handling time, $z = -0.35$, df = 32, p = 0.72; log air exposure, $z = 0.89$, df = 32, p = 0.38; TL, $z = 1.12$, df = 32, p = 0.26).

Reflex Impairment Scores

Reflex 1 scores showed that six of 34 fish exhibited impairment (18%). Of these, five mahseer demonstrated impairment in one reflex (four lost orientation, one lost tail grab) and one mahseer demonstrated impairment in two reflexes (orientation and tail grab). Reflex 2 scores showed that seven of 34 fish exhibited impairment (21%). Of these, four demonstrated impairment in a single reflex (two lost orientation, one each lost tail grab and operculum beats) and three demonstrated impairment in two reflexes (all three lost tail grab and orientation). Of the six fish demonstrating impairment at the reflex 1 timepoint, two fish did not demonstrate impairment during the reflex 2 assessment, three fish demonstrated the same degree of impairment in both scores, and one fish demonstrated impairment in an additional reflex measurement. Three fish that did not exhibit impairment during reflex 1 exhibited impairment in reflex 2. There was no significant difference in impairment frequency between reflex 1 and reflex 2 scores (McNemar's $\chi^2 = 0.06$, df = 1, p = 0.81).

Post-Release Tracking Period

Immediately after release, 29 mahseer were tracked over a 90-min period, with positions established every five min. All tagged mahseer reached the 10-m swim away distance in under a minute (Figure 5.2; Table 5.1). All but four tagged mahseer (14%) completed the 1 m swim away distance in fewer than 15 s and all but five mahseer (17%) completed the 5-m swim away distance in under 20 s. Values for the 10-m swim away time were slightly more dispersed, however only six fish (21%) required longer than 20 s to reach this distance.

Table 5.1 Mean, median, and range of swim away times, the time taken for released mahseer to travel 1 m, 5 m, and 10 m distances from the release site.

	Mean	**Median**	**Smallest Value**	**Largest Value**
Swim Away 1 m (s)	6 s ± 2 s	2 s	1 s	38 s
Swim Away 5 m (s)	8 s ± 2 s	4 s	2 s	42 s
Swim Away 10 m (s)	12 s ± 2 s	7 s	3 s	47 s

The distances travelled by mahseer were higher in the first five min post-release than for ten min post-release (Table 5.2). Both initial measurements (5 min and 10 min post-release) demonstrated higher rates of movement than subsequent measurements, as indicated by ratio distance. In 29% of released fish, the longest distance measured during the travel period occurred during the first 10 min of tracking (largest value, Table 5.2). Movement patterns post-release were not significantly correlated with angling metrics, including angling time, handling time, and air exposure, nor was reflex 2 a significant predictor of increased or decreased movement. Slightly negative relationships were noted in visualizations suggesting increasing TL as a predictor of decreasing movement rates, however, these relationships were not statistically significant either.

Table 5.2 Mean (± standard deviation), median, and range values for tracking variables during the initial post-release tracking period (90 min).

Tracking Variables	Mean	Median	Smallest Value	Largest Value
Distance travelled in first 5 minutes (m)	33 ± 8	18	0	164
Distance travelled in first 10 minutes (m)	47 ± 9	28	0	200
Ratio Distance (m/min)	12 ± 2	11	0	26
Longest distance between measurements (m)	65 ± 8	51	0	164

Diel Movement Tracking Period

Over the 24-hr tracking periods, 28 released mahseer (mean tag days = 16 ± 1, range = 1 tag day – 43 tag days) were tracked for an average of 19 hrs (range = 7 hrs – 23 hrs). The mean distance mahseer travelled per session was 376 m ± 38 m (range = 25 m – 1221 m), with a mean distance per hr of 50 m/hr ± 5 m/hr (range = 9 m/hr – 209 m/hr). There were three peaks of movement over the 24-hr time period, as measured by the longest distance travelled between measurements (m): one peak occurring in the late morning (0800 hrs – 1000 hrs), one peak occurring in the late afternoon (1400 hrs – 1900 hrs), and a smaller peak during the middle of the night (0200 - 0400 hrs; Figure 5.4). Plots of the data suggested that there was a negative linear relationship between tag days and both dependent variables (distance travelled per hr [m], longest distance travelled between measurements per session [m]) such that fish with fewer tag days moved less, but these relationships were not statistically significant when controlling for length (TL, mm; Figure 5.5).

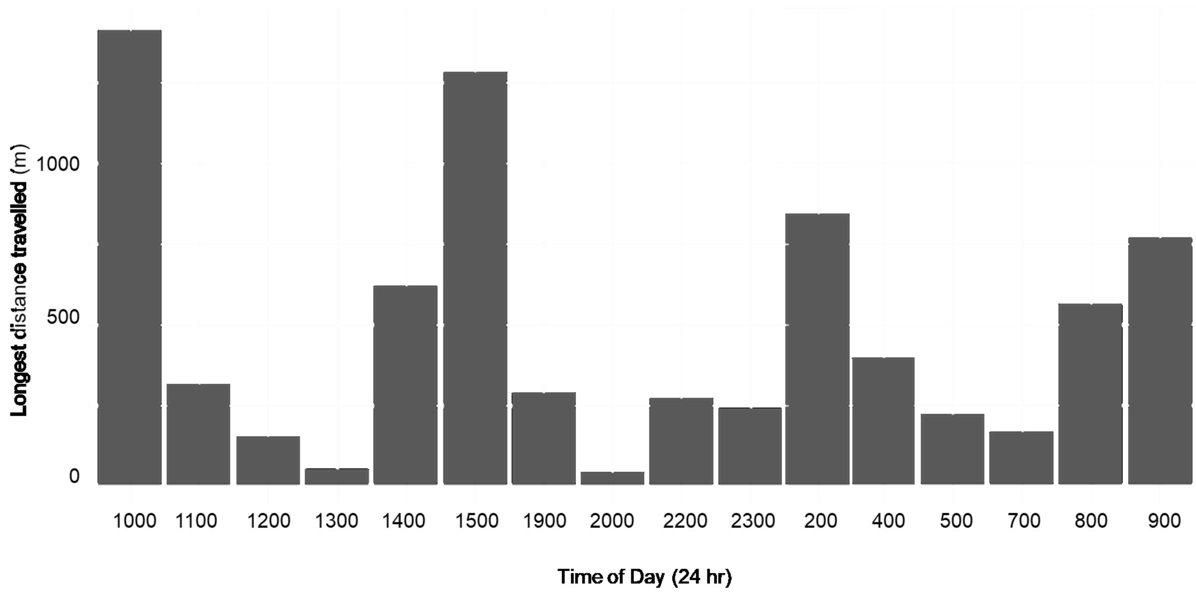

Figure 5.2 The longest distance travelled (m) by released mahseer per tracking session according to the time of day they occurred (using a 24hr clock). There were three peaks of movement over the 24-hr time period, as measured by the longest distance travelled between measurements (m): one peak occurring in the late morning (0800 – 1000 hrs), one peak occurring in the late afternoon (1600 hrs), and a smaller peak during the middle of the night (0200 hrs).

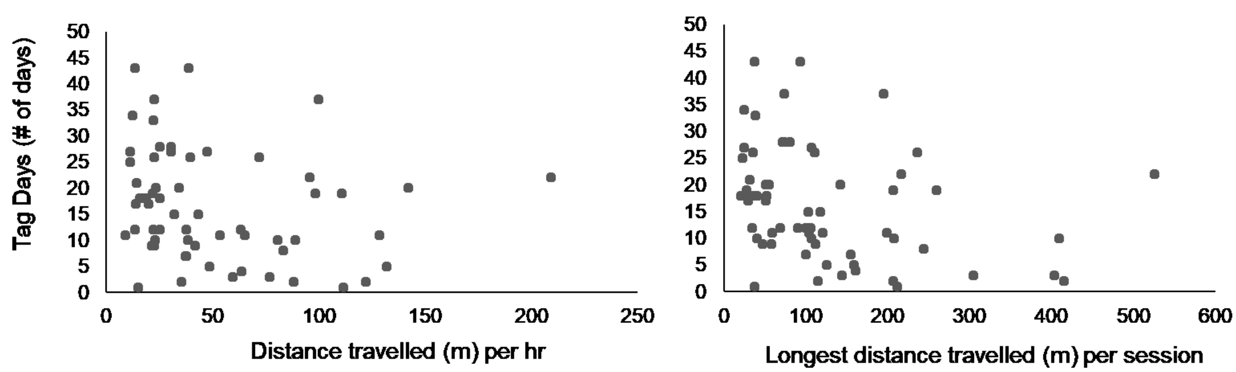

Figure 5.3 Relationship between the linear distance travelled (m) per hour and the number of days since tagging is shown at left, and the relationship between the longest distance travelled (m) during the tagging sessions and the number of days since tagging is shown at right. Slightly negative tendencies in both images demonstrate that fish with fewer tag days were likely to move more that fish with more tag days, and were slightly more likely to exhibit longer travel distances, however neither of these relationships were statistically significant.

Daily Position Tracking

Of a total 60 possible tracking days, the average tracking period was 32 tracking days (range = 1 – 57 tracking days). As noted in the methods section, all mahseer remained in the river reach where they were caught (post-release) with two exceptions. The exceptional events involved an occasion wherein one mahseer left its home reach and travelled 2 km upstream during the onset of pre-monsoon thunder showers, but returned the next morning. On the second occasion, during the onset a period known as 'mango showers' where daily rains that coincide with mango harvest season follow the dry season, multiple mahseer were tracked to an aggregation in the middle of the study reach that lasted for approximately 18 hours. All fish returned to their original locations following aggregation dispersal. To my knowledge, this is the first description of such an event for *T. khudree*.

Discussion

The results of this study provide further evidence supporting the robustness of blue-finned mahseer to C&R activities, but include important considerations for angling and handling behaviours, and offer the first glimpse into post-release movement patterns of the species. Studies examining the consequences of C&R are an integral part of proactive fisheries management (Cooke and Schramm 2007), particularly when C&R fisheries target endangered or migratory species and species prone to post-release predation (e.g., Thorstad et al. 2007, Danylchuk et al 2007). Sub-lethal disturbances and post-release behaviour are understudied components of C&R (Cooke et al. 2013) that should be considered important research for the management of any species whereby C&R activities are presented as a conservation strategy.

That none of the angling variables proved to be significant predictors of reflex or behavioural impairment suggest that further research to identify factors or interactive influences that contribute to relative changes in stress response among mahseer is warranted. There were no significant differences between reflex 1 scores (accounting for reflex impairment arising from the angling process, including air exposure) and reflex 2 scores (accounting for reflex impairment arising from the combination of the angling and handling process, including tagging) in this study. While this suggests that mahseer were not significantly more impaired by the handling and tagging process than by the angling process, the impairment rate (18% for reflex 1, 21% for reflex 2) confirms that angling activities are stressors for this species. As angling and handling times were all within what would be considered reasonable, "real world" timelines for mahseer of similar size, it is reasonable to conclude that use and promotion of best practices that minimize angling and handling time, such as choosing appropriate gear to minimize unnecessarily fight times (Cooke and Suski 2005) and handling fish properly to reduce stress (e.g., minimize air exposure, Cook et al. 2015) be recommended for this species.

Using reflex impairment indicators to predict mortality and measure impairment in fishes allows researchers to gather data quickly and with minimal disturbance (Cooke et al. 2012), and can also be valuable to anglers. For both reflex 1 and reflex 2 scores measured in this study, impairment in mahseer appeared to follow a pattern such that orientation was typically the first reflex lost. Mahseer that exhibited impairment in two reflexes lost orientation and tail grab. This finding accords with previous research on the same species (*T. khudree*, Bower et al. 2016) and other species (*Albula vulpes*, Brownscombe et al. 2013), and may be of particular value to anglers, who may use the lack of regularity of operculum beats as an indicator that a mahseer they have caught is likely to be highly impaired and should be handled and released with caution and care. For example, anglers who note the presence of irregularity in operculum beats should consider foregoing photo-taking, or at minimum ensure that the process is brief and occurs with the fish submerged in water.

Angling and handling time showed a positive linear relationship with swim away times, particularly the time taken to swim 1 m and 5 m away from the release site. This relationship was not statistically significant once fish length was controlled for, which suggests, intuitively, that larger fish were subject to longer angling and handling times, and took longer to leave the release site. Similarly, while mahseer tended to be most active in the first ten min post-release, a slightly negative relationship between post-release movement rates and total length indicated that larger fish moved less during the first ten min post-release. This suggests that while post-release behaviour alterations are minor under similar conditions, they do occur and may be more pronounced in larger mahseer. Anecdotally, trophy-sized mahseer are also the most likely to suffer from post-release predation by crocodiles (Aiyappa C.P., personal communication). That mahseer moved more in the earlier post-release period (i.e., the first 10 min) is consistent with the results of a study by Thorstad et al. (2003), who found that the post-release period for two large cichlid species on the Zambezi River featured increased movement rates compared to post-recovery movement rates. Only two fish larger than 15 kg were landed during this study, but this finding combined with anecdotal suggestions that post-release predation of large mahseer is a possibility lends support to the need for further study exploring the responses and fate of trophy-sized mahseer post-release, as these fish are the most highly-prized and sought after by local anglers, and are likely the most highly fecund.

The diel movement studies included mahseer tagged from one to 43 days previously, and this period likely covers the return to metabolic and behavioural baseline (pre-angling). Though a recovery profile for mahseer has yet to be generated, recovery profiles for other species have found that blood lactate returns on baseline levels in hours, not days, depending on conditions (e.g., approximately 6 hrs in rainbow trout [*Oncorhynchus mykiss*] held in still water and approximately 4 hrs for rainbow trout held in flowing water, Milligan et al. 2000). In simulated recreational angling captures where fish were exercised to exhaustion, heart rates of adult migrating coho salmon (*Onchorhynchus kisutch*) required 16 hrs to return to baseline levels compared to 7.6 hrs after simulated beach seining (Donaldson et al. 2010). Results of analysis of the diel movement tracking period suggested that fish with fewer tag days moved more over the course of 24 hrs than fish tagged less recently (also consistent with Thorstad et al. 2004). As with the findings of the immediate post-release period, these results were not statistically significant once fish length was accounted for. This may indicate that differences in movement are linked more to size- or age-based behavioural differences than to catch-and-release activities. Indeed, during the daily position tracking, I noted that smaller mahseer were more likely to be visibly congregating together in shallow water, whereas larger mahseer were never seen in these groups (S. Bower, personal observation).

I acknowledge that the study took place over a single season, suggesting that this study would fail to pick up longer term variation that could arise resulting from changes in temperature regime, or other long-term patterns (e.g., as seen in salmonids, Raby et al. 2016). However, I specifically chose to conduct this study during the most extreme of the annual conditions (highest air and water temperatures, combined with lowest flows) for this reason. Given the lack of evidence of sub-lethal consequences arising from combined C&R and tagging activities during the time of year with highest water temperatures and lowest flows, I feel it is reasonable to conclude that mahseer behaviours are not likely to be altered by C&R activities, particularly when best practices (minimizing handling and air exposure times) are employed by anglers.

Conclusion

The conservation value of considering sub-lethal consequences of fisheries interactions is particularly important for recreational fished species that are considered threatened or endangered. While *T. khudree* are listed as “Endangered” in their native range (Raghavan 2011), it would be disingenuous to describe the study group as Endangered as they represent a stocked population, one that has possibly contributed to the decline of another native mahseer species in the Cauvery River (Pinder et al. 2015). However, as wild populations of *T. khudree* face marked decline in their native range (Raghavan 2011), these hatchery-bred specimens may be the most closely-related stable population. As such, the research conducted on this species may prove invaluable in supporting the evidence base to indicate that these species are robust to C&R under similar conditions and could support a C&R fishery to promote conservation and reintroduction of the species in its native waters. My work suggests that behavioural consequences of C&R activities to mahseer are likely to be minor, provided anglers use appropriate gear and recommended angling and handling practices. However, the results also indicate that mahseer behaviour after release may be influenced by size, suggesting research on behavioural consequences of C&R should include studies of trophy-sized mahseer. Identifying typical patterns of movement after C&R activities in mahseer not only helps to support sustainable management of this species from a fisheries perspective, but also provides valuable baseline data to support a conservation behaviour approach. Improved understanding of habitat use and behavioural responses to key threats such as fragmentation and stocking regimes can help to predict population-level responses to ongoing changes in the environment (Sutherland 1998).

Acknowledgements

I would also like to extend sincere gratitude to the Karnataka Fisheries Department and the members and governing council, including the Fishing Subcommittee, of the Coorg Wildlife Society for their support and cooperation throughout this study. In particular, the support of the chairman of the Fishing Subcommittee, Aiyappa C.P., and that of Sandeep Chakrabarti, Derek D'Souza, and Raja P.K. were integral to the success of this research. I also greatly appreciate the efforts of anglers who joined us on the river throughout the project, including Ambily Nair, Alexis Greenwood, Marcus Greenwood, Saravanan Shanmugam, Yohann De Souza, Dayan Mandappa, Bopanna Pattada, Ajay Bopanna Kodandera, Vinnay Appanna, Jagrath Belliapa Chendanda, Maya D'Souza, Shyam Aiyappa, and Devaiah Chendanda. It was an honour to share the river with all of you.

Chapter 6. Consequences of simulated multiple catch and release events on reflex impairment, ventilation rate, and body condition in *Tor khudree*

Abstract

As catch and release becomes more popular and angling pressure increases, it is likely that fish in popular catch and release fisheries will experience catch and release events on more than one occasion ("multiple capture"). Anecdotal reports from anglers suggest that blue-finned mahseer (*Tor khudree*) in WASI Lake, Karnataka, India commonly experience multiple capture events that are closely timed together, i.e., often on the next day. To determine whether multiple capture events were likely to result in cumulative physiological effects compared to single capture events, I quickly angled (i.e., landed in <150 seconds) 124 blue-finned mahseer and placed them in one of four simulated capture treatment groups: control, air exposure (60 seconds), chase (300 seconds), or a combination of air exposure and chase. Mahseer were held overnight in a net pen, and subjected to a second (N=91) or third (N=60) instance of simulated capture. My results indicate that while air exposed blue-finned mahseer showed significantly decreasing ventilation rates across simulated capture events, and mahseer in the chase treatment showed significantly increasing ventilation rates across simulated capture events, reflexes were not significantly more impaired for any treatment groups or across treatment days (days 1, 2, or 3). I conclude that closely timed instances of multiple catch and release events are likely to result in cumulative physiological effects in mahseer, but that these effects are not likely to result in significant increases in reflex impairment or post-release mortality provided that fish are handled in ways consistent with best handling practices.

Introduction

Catch and release (C&R) fishing refers to the capture and subsequent release of a fish back into the water, presumably unharmed (Arlinghaus et al. 2007). C&R has been applied as a voluntary or mandatory management tool for recreational fishing of numerous threatened species (e.g., *Hucho taimen*, Jensen et al. 2009; and see Cooke et al. 2016 for additional case studies) and an estimated 60% of all fish captured during recreational fishing activities are released (Cooke and Cowx 2004). During the C&R process, fishes can experience a range of physiological alterations related to angling activities ranging from minor temporary increases in blood lactate and glucose to post-release mortality if physiological stress exceeds biological thresholds (Arlinghaus et al. 2007). Fish may experience behavioural alterations (such as reduced movement or feeding behaviour) that can result in increased rates of post-release predation (e.g., *Albula vulpes*, Danylchuk et al. 2007) or decreased success in crucial life history behaviours (such as migration, Thorstad et al. 2007). This variability in potential response has led to calls for research into species-specific responses to C&R (Cooke and Suski 2006) and improved understanding of how a range of angler behaviours and environmental conditions contribute to these responses (Cook et al. 2013), particularly as stress may be cumulative (Barton et al. 1986). Also among these knowledge gaps is the question of how many fish experience capture on multiple occasions (‘multiple capture’) and whether any negative physiological or behavioural effects arise as a result of multiple capture that are not evident after single instances of capture (e.g., recommended by Bartholomew and Bohnsack 2005; Patterson et al. 2017).

Instances of multiple capture occur over short (e.g., Nelson et al. 2005) and long (e.g., Cline et al. 2012) time frames and can result in numerous physiological and behavioural changes in individual fish and potentially fish populations (e.g., changes to habitat selectivity for *Esox* *lucius* populations were noted in single capture event study, Klefoth et al. 2011). Some studies have demonstrated that multiple capture events can influence individual fish growth (e.g., Cline et al. 2012), though others have found no apparent effects of multiple capture on mortality rates (e.g., in *Thymallus arcticus*, Clark et al., 1991). However, Nelson et al. (2005) found that while as many as three instances of multiple capture did not impact mortality rates or spawning success in steelhead (*Oncorhynchus mykiss*), hatchery fish were more likely to be recaptured than wild fish. Similarly, Garrett (2002) found that angling vulnerability in *Micropterus salmoides* could be selectively bred for and that individuals vulnerable to angling were more likely to be caught on multiple occasions. Given the increasing use of C&R as a management tool and the selective pressures exerted on fish by angling activities, the impact of multiple capture events on mortality rates and sublethal effects should be considered a priority for key C&R populations, particularly threatened species, and populations subject to high fishing pressure.

Measuring the effects of multiple capture in C&R scenarios involves several challenges inherent to C&R research, including difficulties establishing true controls (such as for mortality estimates, Pollock and Pine 2007) and a reliance on tools such as holding pens and capture simulation to enable data-gathering during the recapture period. Holding pens have been found to result in elevated plasma stress (e.g., elevated plasma cortisol and elevated plasma glucose, Donaldson et al. 2011), and their use can involve extensive and repeated handling (Cooke et al. 2013), suggesting that it is difficult to disentangle effects of C&R from effects of holding. Similarly, as ensuring a high rate of genuine instances of multiple capture can be challenging in a field study scenario, simulation studies can be used to ensure adequate data points over a short term. However, simulation studies can result in a disconnect between simulated and genuine outcomes (Cooke et al. 2013; Cooke et al. In Press). Despite these potential challenges, the use of simulated angling events and holding pens are beneficial to the study of C&R impacts by allowing researchers to control variables and gain visual access to 'released' fish, and may be unavoidable when attempting to quantify the effects of closely timed multiple capture events.

The mahseer C&R recreational fishery of the Cauvery River in South India is likely the best known recreational fishery in India. Mahseer species throughout India are currently under threat from several anthropogenic stressors, including agricultural pollution, hydropower development, invasive species, and overfishing (Everard and Kataria 2011). Currently, the most commonly caught mahseer species on the Cauvery River is the blue-finned mahseer, a species that may not be native to the Cauvery River basin, but is listed on the IUCN RedList as 'Endangered' (Raghavan 2011) due to rapidly decreasing populations throughout its home range.

The Wildlife Association of South India (WASI), is a conservation-oriented organization that manages one of the two managed stretches on the Cauvery River where C&R of mahseer is mandatory. Their main lodging and fishing area consists of two man-made lakes (WASI Lakes and Forbes Sagar) situated along a canal that diverts water from the Cauvery River. WASI members can rent two cottages on site, and pay daily license fees to fish from WASI Lake and Forbes Sagar. The most common target species for WASI anglers include mahseer, rohu (*Labeo rohita)*, catla (*Catla catla*), and snakehead (*Channa* spp.). Previous studies of mahseer responses to C&R have indicated that *T. khudree* are physiologically (Bower et al. 2016a) and behaviourally (Bower et al. In Review) resilient to common C&R practices, but have noted that prolonged angling times and air exposure may result in increased impairment, particularly in larger fish. Anecdotal reports of fishing activity at the WASI site have suggested mahseer were likely to experience multiple capture events over a short term (i.e., a few days to a week), which indicated that an additional study of multiple capture events would be of value. Thus, I simulated multiple capture events at this location to test the hypothesis that the number of capture events would influence post-release impairment in mahseer. I predicted that *T. khudree* were unlikely to experience significant impairment as a result of closely-timed simulated multiple capture events. I further predicted that there would be no significant differences in reflex impairment or ventilation rates across treatment days. However, as mahseer have demonstrated a sensitivity to air exposure and extended angling times (Bower et al. 2016), I predicted that fish in air exposure and chase treatment groups would have significantly higher reflex impairment and significantly different ventilation rates than those in the control group, and that mahseer in the combination treatment group would have significantly higher reflex impairment and significantly different ventilation rates than those in air exposure and chase treatment groups. Given my objective, the combination of short time frames and the relevance of studying multiple capture instances for this fishery suggested that the use of simulated angling processes and holding pens were warranted.

Methods

Study Site and Angling Practices

Angling and sampling took place in a small, man-made impoundment along the Cauvery (Kaveri) River known as WASI Lake (12.288979 º N, 77.155393 º E; Figure 6.1) from May 6 to June 7, 2016. Angling activities took place from shore, during daylight hours (ranging from 0830 hrs to 1900 hrs). Fish were angled using light-weight spinning gear and method feeder rigs packed with busa (a mixture of flours, oils, cow feed, and corn), the most commonly used method for catching mahseer in this area (Figure 6.2). To ensure that initial angling processes resulted in as little added physiological stress as possible, mahseer were landed in under 2.5 min (maximum time from hooking to unhooking in processing pool) in an attempt to minimize physiological disturbance prior to treatment (Kieffer 2000). Thus, any fish not landed within this timeframe (N=3) were excluded from analysis and released. Water temperatures during the multiple capture simulation study averaged 30 ± 0.6 ˚C (range: 28 ˚C – 32 ˚C).

Figure 6.1 Map of the Cauvery River, Karnataka, India, with the WASI Lakes and Forbes Sagar location shown (star) in the inset, as a diversion of the Cauvery River near Shivanasamudra Falls.

Figure 6.2 Blue-finned mahseer caught at the WASI Lake study site commonly fall in the size range seen in the study (300 mm – 586 mm [total length]; left), and are typically caught using method feeder rigs (top right), packed with a grain and corn-based bait known as busa (bottom right).

Simulated Multiple Capture Procedures

On placement in the processing pool, each mahseer was measured for total body length (TL, mm), and a temporary uniquely numbered identification tag (5 cm length, with a 1 cm x 1 cm fine fabric tag; Avery Dennison, Westboro, MA, USA) was inserted into the dorsal musculature behind the dorsal fin using a Mark III Fine Fabric Pistol Grip tagging gun (Floy Tag, Seattle, WA, USA). Each mahseer was then assigned to one of four treatment groups: control, air exposure, chase, or combination (chase and air exposure). Duration of the treatments was based on angling times common to the location. Fish placed in the control group were left undisturbed in a mesh-ended, black holding bag (75 cm in length; Dynamic Aqua Ltd., Vancouver, BC, Canada) in the processing pool for 5 min. Fish placed in the air exposure treatment group were left undisturbed in the holding bag for 4 min, then suspended out of water (with all water drained out of the holding bag) for 1 min. Fish in the chase treatment group were made to swim vigorously around the processing pool for 5 min before being placed in the holding bag. Fish in the combination treatment group were made to swim vigorously around the processing pool for 5 min before being placed in the holding bag, then suspended out of water (with all water drained out of the holding bag) for 1 min.

After treatment, each mahseer was measured for reflex impairment using Reflex Action Mortality Predictors (RAMP; Davis 2010) and ventilation rate (operculum beats/ 10 sec) while in the recovery bag. RAMP measurements were scored on a binary basis (0,1) according to whether the fish exhibits the behaviour (a score of 0, or unimpaired) or does not exhibit the behaviour (a score of 1, or impaired). Scores from each impairment measurement were then summed to develop an overall impairment score ranging from 0 – 1 for each fish (e.g., see Brownscombe et al. 2013). The reflex impairment measurements applied in this study were ‘tail grab’, the presence of burst swimming reflex activity within 3 sec of being grabbed by the caudal peduncle; ‘orientation’, the presence of re-orienting capability within 3 sec of being placed upside down in water; and ‘operculum beats’, the regularity and steadiness of operculum beats (as opposed to irregular or unsteady beats; Davis 2010). In this study, I noted that many mahseer released bubbles from the gills or demonstrated a brief hiccup in operculum beats during processing, however, if the rate of operculum beats was steady I did not consider this a demonstration of impairment. Ventilation rate is typically used as a non-invasive measurement of energy consumption in fish (e.g., Millidine et al. 2008), however it is also used as a measurement of sympathetic response to stress in fishes (Barreto and Volpato 2011). In this study, I used ventilation rate as a complementary whole-body stress indicator to compare and supplement impairment scores measured with RAMP (Sopinka et al. 2016 recommend the use of multiple whole-body stress indicators).

After treatment and measurements, each fish was brought from the processing pool to a net pen (1.5 m x 2 m x 3 m) in the holding bag and left in the net pen overnight. The net pen was secured at the top with a mesh lid covered with an 8-cm foam layer to prevent injury to fish attempting to jump free. Mahseer held overnight were supplied with food in the form of busa.

A high rate of overnight escapes over the first week of the study led me to further secure the net pen at night by loop stitching the net pen shut with oiled twine. Though small mahseer such as the ones sampled during this study have been observed congregating in large groups (Bower et al. In Review) which led us to believe holding effects from a group of 15 small mahseer held overnight in the net pen would be insignificant, this proved not to be the case. On effectively securing the net pen and preventing a high rate of escapes, I noted that mahseer held overnight exhibited severe signs of holding effects, including clouded eyes and complete slime loss. These fish were immediately released (May 18), excluded from further analysis, and a new maximum of 10 mahseer per day were retained in the pen. To account for holding effects, I also retroactively instituted (based on my field notes) a condition score (e.g., see Campbell et al. 2009). The condition score ranged from 0 – 3, where 0 indicated a fish in excellent body condition (no external damage). A score of 1 was given to mahseer showing minor external damage, defined for this study as exhibiting one or more of the following: 1 – 2 fins tattered and/or frayed, ≤ 3 scales abraded, 1 or fewer abrasions at nares or along dorsal ridge, and minor slime loss. A score of 2 was given to mahseer showing moderate external damage, defined as exhibiting one or more of the following: 3 – 4 fins tattered, 3 – 5 scales abraded, > 1 abrasions at nares or along dorsal ridge, eyes showing early signs of clouding, and moderate slime loss. A score of 3 was given to mahseer showing major external damage, defined as exhibiting one or more of the following: > 5 fins tattered, > 5 scales abraded, distinct abrasions at nares or along dorsal ridge, eyes cloudy, and major slime loss. Mahseer captured prior to development of the condition score for whom field notes did not adequately describe body condition were assigned a score of 'na'.

Fish held overnight in the net pen were processed the following morning from 0730 to 0830. Day 2 and Day 3 processing excluded the initial angling event, body size measurement, and temporary tag placement. Mahseer were removed from the net pen, placed into the holding bag and brought to the processing pool. Fish were kept in the same treatment group throughout the experiment, and ventilation rates and impairment measurements were performed in the same manner on both Day 2 and Day 3. All fish had their temporary tags removed and were released after measurements on Day 3. All experimental manipulations performed during this study were conducted in accordance with Canadian Council of Animal Care regulations under Carleton University Protocol #101005.

Statistical Analyses

Results were compared both across days and within treatment groups. Treatment was used as a between-subjects factor and day was treated as a within-subjects factor, and all models included treatment*day as a crossed factor. As ventilation rate was normally distributed, a linear mixed-effects model (lme4 package, Bates et al. 2015) was used determine whether ventilation rate differed significantly for mahseer among Days 1, 2, and 3 and across treatment groups. As the random factor (subject) did not contribute significantly (i.e., was 0) to model outcomes, nonlinear, multinomial models (multinom, nnet package, Venables and Ripley 2002) were used determine whether impairment and condition scores differed significantly for mahseer among Days 1, 2, and 3 and across treatment groups to avoid condensing variables to binary distributions. The chosen models can perform in the same manner as traditional repeated measures models (i.e., repeated measures Anova) but are more robust to non-normally distributed variables, imbalanced variables, and allows for unequal variance in within-subjects variables (Clark 2017), all attributes which were relevant to this analysis. All analyses were conducted in R (version 3.3.3, R Core Team 2016).

Results

Simulated Multiple Capture Procedures

All 124 mahseer caught were subjected to the first simulated capture event. Of these, 33 escaped either from the net pen or during processing events. The majority of escapees were those placed in the combination treatment category. Four of these escaped fish were later caught again during angling activities, but were released on identification as a recapture. There were 91 fish in total subjected to simulated multiple capture processes: all 91 mahseer were held overnight for a single night and subjected to a second simulated angling processes and 60 of these mahseer were held overnight for a second night and subjected to a third simulated angling process prior to release. Mahseer included in the study ranged from 300 mm – 586 mm (TL). The mean TL decreased slightly over the course of the holding period, but remained within 3 mm throughout the study period and did not differ significantly among treatment groups (F= 0.468, df = 119, p = 0.468; Table 6.1).

Table 6.1 Mean length (total length [TL], mm), Impairment score, ventilation rate, and condition score across all treatment groups (control, air exposure, chase, combination) by day. Mean length and ventilation rate values are presented ± standard deviation. Impairment (0, 0.33, 0.66, 1) and condition scores (0, 1, 2, 3) are presented as counts for each level, with associated percentage of mahseer represented to enhance count meaning.

	Mean TL (mm)	**Impairment Score (0, 0.33, 0.66, 1)**	**Ventilation Rate (beats/ min)**	**Condition Score (0, 1, 2, 3)**
Day 1	369 ± 50	0: 111 (90%)	90 ± 16	0: 118 (95%)
		0.33: 12 (9%)		1: 6 (5%)
		0.66: 1 (1%)		2: 0
		1: 0		3: 0
Day 2	368 ± 48	0: 84 (92%)	98 ± 17	0: 21 (26%)
		0.33: 5 (5%)		1: 30 (37%)
		0.66: 2 (2%)		2: 22 (27%)
		1: 0		3: 8 (13%)
				n/a: 10
Day 3	366 ± 47	0: 50 (83%)	108 ± 18	0: 13 (22%)
		0.33: 8 (13%)		1: 15 (26%)
		0.66: 1 (2%)		2: 17 (29%)
		1: 1 (2%)		3: 13 (22%)
				n/a: 5

The majority of fish in all treatment groups failed to demonstrate reflex impairment (score 0; Table 6.1, Figure 6.3). There was a slight trend towards increased impairment scores on

Days 2 and 3 (Figure 6.3), however, impairment scores on Day 2 were not noticeably higher or lower than those of Day 3. Thirteen mahseer (11%) demonstrated reflex impairment after the first simulation (Day 1; Table 6.1). Of these, twelve demonstrated impairment in a single reflex (five lost tail grab, one lost orientation, and six lost regular operculum beats). The mahseer that exhibited impairment in two reflexes lost tail grab and orientation. Seven fish (8%) demonstrated impairment after the second simulation (Day 2; Table 6.1). Of these, five showed impairment in a single reflex (two lost tail grab, one lost orientation, and two lost regular operculum beats). The two fish that showed impairment in two reflexes lost tail grab and orientation, and tail grab and regular operculum beats. Ten mahseer (17%) demonstrated impairment after the third simulation (Day 3; Table 6.1). Eight fish demonstrated impairment in a single reflex (one lost tail grab and seven lost regular operculum beats). One fish lost orientation and operculum beats, and another fish lost all three reflexes measured. Mean ventilation rates increased throughout the holding period, rising from 90 beats per min ± 16 beats per min on Day 1 to 108 beats per min ± 18 beats per min on Day 3 (Table 6.1; Figure 6.4). Like patterns observed in reflex impairment score, patterns in condition scores showed increasing values for all treatment groups across all days (Table 6.1; Figure 6.5). Unlike reflex impairment score, condition scores were clearly higher on Day 2 than on Day 1 and higher on Day 3 than on Day 2 (Figure 6.5).

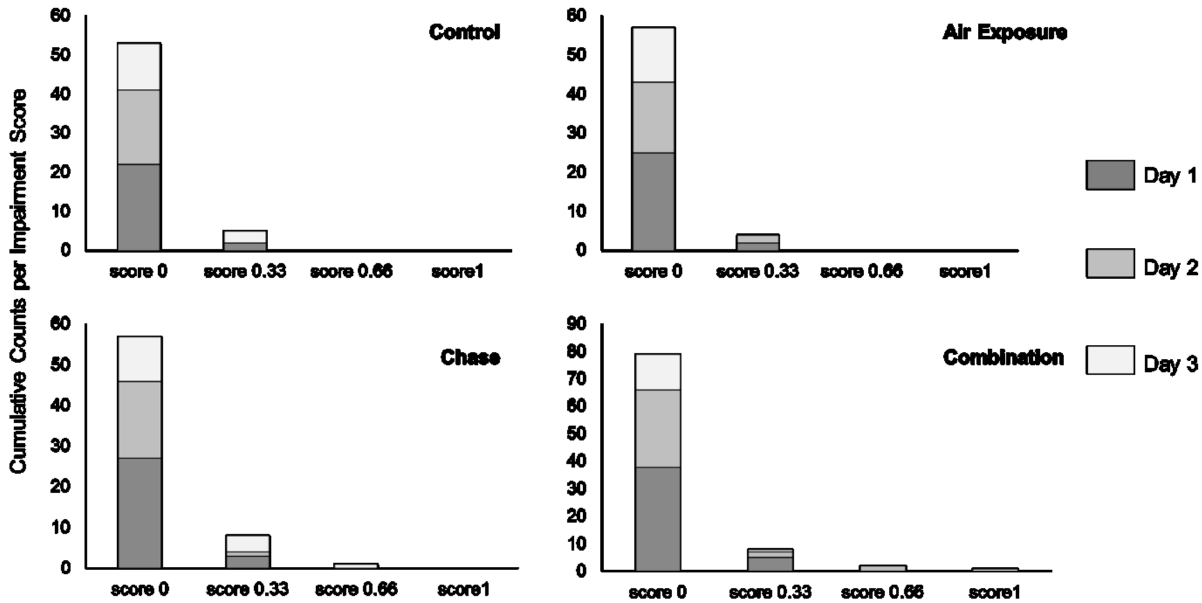

Figure 6.3 Cumulative score counts for reflex impairment scores (0, 0.33, 0.66, 1) of Day 1 (dark grey), Day 2 (medium grey), and Day 3 (white) simulated capture events for (clockwise from top left) control, air exposure, combination, and chase treatment groups.

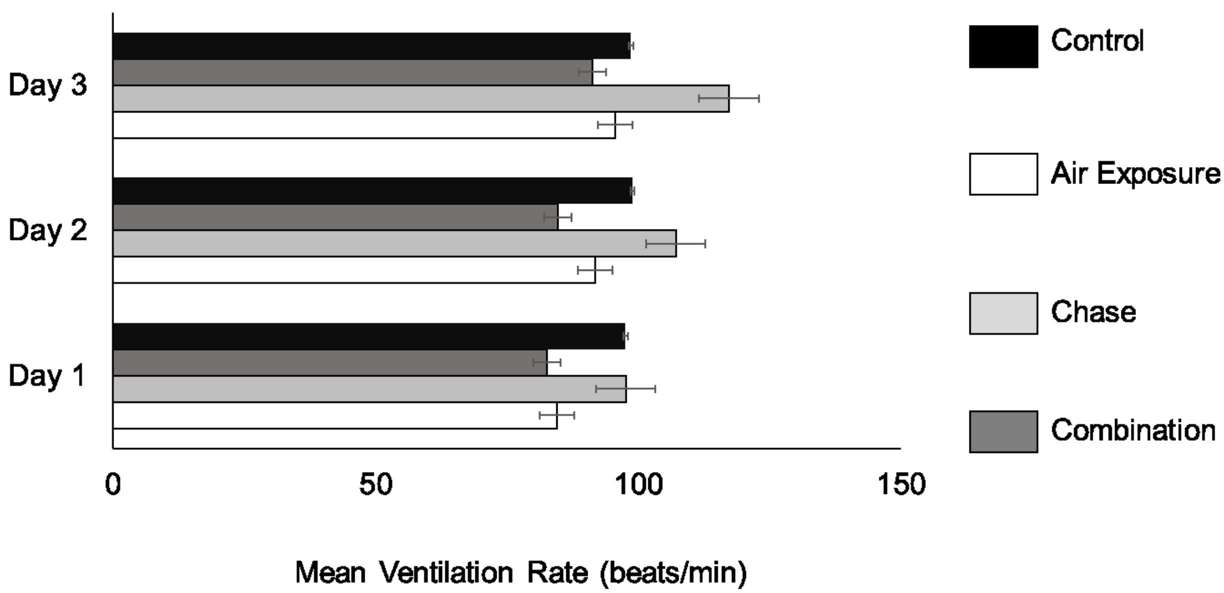

Figure 6.4 Mean ventilation rates of control (black), air exposure (white), combination (light grey), and chase (medium grey) treatment groups for simulated capture events on (from bottom to top) Day 1, Day 2, and Day 3.

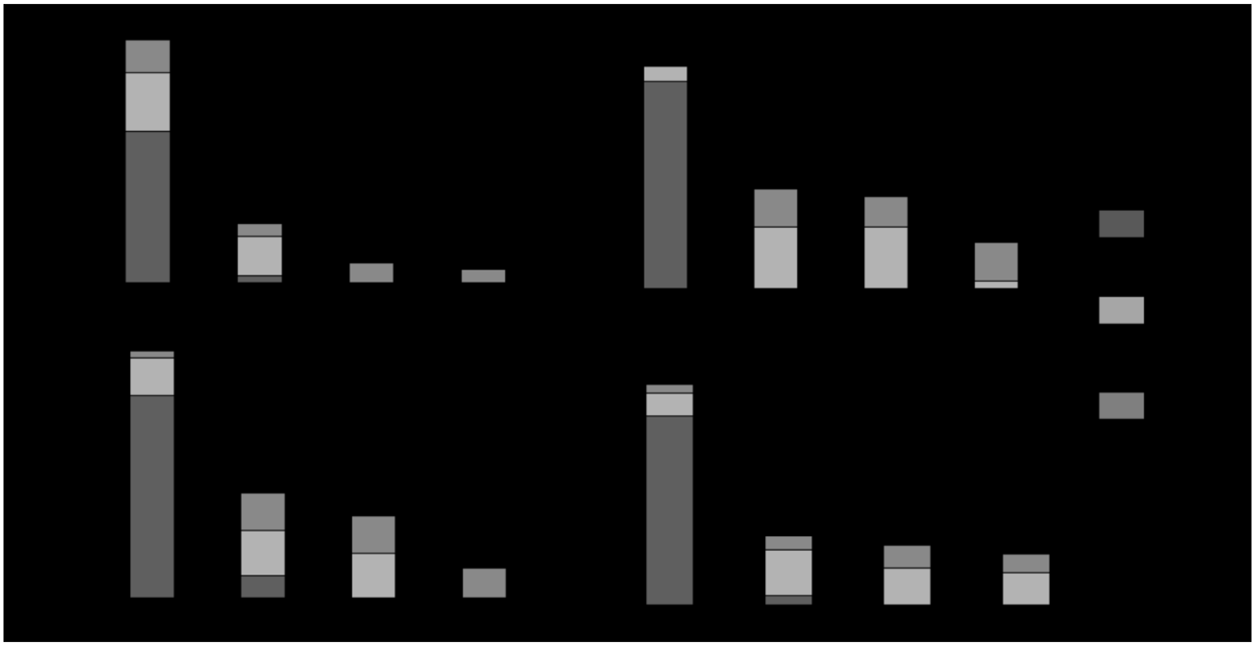

Figure 6.5 Cumulative score counts for condition scores (0, 1, 2, 3) of Day 1 (dark grey), Day 2 (medium grey), and Day 3 (white) simulated capture events for (clockwise from top left) control, air exposure, combination, and chase treatment groups.

Treatment Groups

On landing, mahseer were separated into one of four treatment groups: 27 were placed in the air exposure treatment group, 30 were placed in the chase treatment group, 43 were placed in the combination treatment group, and 24 were used as a control group.

Impairment scores indicating no reflex impairment (score 0) were the most common for all treatment groups, with a few fish in each group demonstrating impairment of one or more reflexes across all days (Table 6.2; Figure 6.3). Mahseer in air exposure and control groups registered impairment in only a single reflex, while mahseer in chase and combination groups registered impairment in two or more reflexes on Day 2 (combination) and Day 3 (chase) only

(Table 6.2; Figure 6.3). In the chase group, mahseer exhibited impairment in none or one reflex on Day 1 and Day 2 and exhibited impairment in none, one, or two reflexes on Day 3. In the combination group, mahseer exhibited impairment in none or one reflex on Day 1, in none, one, two, or three reflexes on Day 2, and exhibited no reflex impairment on Day 3.

Table 6.2 Mean total length (TL, mm), impairment score, ventilation rate, and condition score per treatment group (control, air exposure, chase, combination) by day. Mean length and ventilation rate values are presented ± standard deviation. Impairment (0, 0.33, 0.66, 1) and condition scores (0, 1, 2, 3) are presented as counts for each level, with associated percentage of mahseer represented to enhance count meaning.

Treatment Group	**Mean TL (mm)**	**Impairment Score (0, 0.33, 0.66, 1)**	**Ventilation Rate (beats/ min)**	**Condition Score (0, 1, 2, 3)**
Control Day 1 *(N=24)*	372 ± 37	0: 22 (92%) 0.33: 2 (8%) 0.66: 0 1: 0	98 ± 19	0: 23 (96%) 1: 1 (4%) 2: 0 3: 0
Control Day 2 *(N=19)*	374 ± 39	0: 19 (100%) 0.33: 0 0.66: 0 1: 0	99 ± 18	0: 9 (60%) 1: 6 (40%) 2: 0 3: 0 na: 4
Control Day 3 *(N=15)*	375 ± 42	0: 12 (80%) 0.33: 3 (20%) 0.66: 0 1: 0	99 ± 20	0: 5 (42%) 1: 2 (17%) 2: 3 (25%) 3: 2 (17%) na: 3
Air Exposure Day 1	376 ± 51	0: 25 (93%) 0.33: 2 (7%)	84 ± 12	0: 27 (100%) 1: 0

(N=27)		0.66: 0		2: 0
		1: 0		3: 0
Air Exposure	376 ± 51	0: 18 (90%)	92 ± 14	0: 2 (11%)
Day 2		0.33: 2 (10%)		1: 8 (42%)
(N=20)		0.66: 0		2: 8 (42%)
		1: 0		3: 1 (5%)
				na: 1
Air Exposure	378 ± 59	0: 14 (100%)	96 ± 13	0: 0
Day 3		0.33: 0		1: 5 (36%)
(N=14)		0.66: 0		2: 4 (29%)
		1: 0		3: 5 (36%)
				na: 0
Chase	374 ± 71	0: 27 (90%)	98 ± 15	0: 27 (90%)
Day 1		0.33: 3 (10%)		1: 3 (10%)
(N=30)		0.66: 0		2: 0
		1: 0		3: 0
Chase	369 ± 67	0: 19 (95%)	107 ± 17	0: 5 (29%)
Day 2		0.33: 1 (5%)		1: 6 (35%)
(N=20)		0.66: 0		2: 6 (35%)
		1: 0		3: 0
				na: 3
Chase	358 ± 46	0: 11 (69%)	117 ± 20	0: 1 (6%)
Day 3		0.33: 4 (25%)		1: 5 (33%)
(N=16)		0.66: 1 (6%)		2: 5 (33%)
		1: 0		3: 4 (27%)
				na: 1
Combination	359 ± 36	0: 38 (88%)	83 ± 13	0: 41 (95%)
Day 1		0.33: 5 (12%)		1: 2 (5%)

(N=43)		0.66: 0 1: 0		2: 0 3: 0
Combination Day 2 *(N=32)*	359 ± 37	0: 28 (88%) 0.33: 2 (6%) 0.66: 2 (6%) 1: 0	85 ± 13	0: 5 (17%) 1: 10 (33%) 2: 8 (27%) 3: 7 (23%) na: 2
Combination Day 3 *(N=15)*	353 ± 39	0: 13 (87%) 0.33: 1 (6%) 0.66: 0 1: 1 (6%)	91 ± 14	0: 2 (14%) 1: 3 (21%) 2: 5 (36%) 3: 4 (29%) na: 1

Mean ventilation rate was lower in air exposure and combination treatment groups than in control and chase treatment groups and mean ventilation rate was higher in the chase treatment group than in the control group (Figure 6.2). Mean ventilation rate remained steady across all three days in the control group (range: 72 – 150 beats/min), and rose slightly across all days for air exposure (range: 66 – 120 beats/min) and combination (range: 66 – 132 beats/min) treatment groups (Table 6.2; Figure 6.2). Mean ventilation rate was highest overall and increased most steeply for mahseer in the chase treatment group (range: 66 – 150 beats/min; Table 6.2; Figure 6.2). The majority of mahseer had low condition scores (0, 1), but higher condition scores (2, 3) were more common in treatment groups other than control (Table 6.2; Figure 6.3). Treatments involving air exposure (air exposure, combination) had the largest number of condition 3 scores (Table 6.2; Figure 6.3).

Combined Multiple Capture and Treatment Effects

The results of the linear mixed effects model indicated that ventilation rate was significantly different among treatment groups and day, and was also significantly different when interactions between treatment and day were controlled for (Table 6.3). Sources of the differences among treatment groups were determined to be between ventilation rate values of chase and air exposure treatments (F = 15.18, df = 3, p <0.001), between combination and chase treatments (F = 15.18, df = 3, p <0.001), and between control and combination treatments (F = 15.18, df = 3, p <0.001). These differences were found to occur across all days, but were more significant between Days 1 and 3 (F = 23.01, df = 2, p < 0.001) than between Days 1 and 2 (F = 23.01, df = 2, p = 0.001) or Days 2 and 3 (F = 23.01, df = 2, p = 0.002). Multinomial model testing showed no significant differences in impairment scores or condition scores between treatment groups or across days.

Table 6.3 Analysis of variance output resulting from mixed-effects model testing of differences in ventilation rate among treatment groups and across days of capture. Ventilation rate was significantly different for both variables, but statistical significance decreased greatly when interactions were controlled for (Treatment*Day).

Response Variable		**df**	**Sum Sq.**	**Mean Sq.**	**F value**	**P value**
Ventilation Rate	Treatment	3	4647.1	1549.0	11.8	< 0.001**
(beats/ min)	Day	2	8338.7	4169.4	31.8	< 0.001**
	Treatment*Day	6	723.7	120.6	0.9196	0.5*

Discussion

My initial predictions that mahseer would demonstrate robustness to simulated multiple capture events but sensitivity to treatment types were not proven correct by hypothesis testing. The results of my study indicate that C&R-induced stressors such as exhaustive exercise and air exposure result in impairment responses in mahseer that were cumulative across instances of multiple capture over a short time period (as indicated by ventilation rate model results), but are unlikely to result in significant reflex impairment that influences post-release mortality rates (as indicated by reflex impairment model results). Measurements of ventilation rate suggested that mahseer do experience significant increases in impairment when subject to closely-timed instances of multiple capture, and further indicate that mahseer that have experienced air exposure (air exposure and combination treatments) are significantly more likely to have lower ventilation rates than fish subjected to vigorous chase only, which are more likely to have significantly higher ventilation rates than mahseer in the control group. However, measurements of reflex impairment designed to predict mortality (Davis 2010) indicate that mahseer experience only minor increases in impairment when subject to closely-timed instances of multiple capture.

The findings of my study may also reflect masked effects of C&R-induced stressors that were more clearly defined by measurements of ventilation rate than by reflex impairment. For example, it would typically be expected that fish in the combination treatment would exhibit the most severe impairment because air exposure is known to exacerbate stress responses (reviewed in Cook et al. 2015). However, air exposure has been found to result in lowered ventilation rate in fishes (in studies examining interactive effects with water temperature, e.g., Gingerich et al. 2007; Gale et al. 2014), while ventilation rate has been shown to increase in relation to numerous other stressors, such as exercise (e.g., in Nile tilapia [*Oreochromis niloticus*], Barreto and Volpa

2011). In this study, mahseer in the combination treatment had slightly higher ventilation rates than mahseer in the air exposure group, and significantly lower ventilation rates than mahseer in the chase group. This unexpected result may indicate that these two stressors interact in mahseer such that these opposing effects are masked when measured by whole body indicators. Alternatively, Barreto et al. (2004) suggested that ventilation rate measurements may be less reliable for measuring the severity of a stressor than for identifying the presence of a stressor; however, given the clear trends indicated by ventilation rate measurements in this study I believe this caveat does not apply. Additionally, there may be an unstudied interaction occurring in mahseer in the form of escape response. Barreto et al. (2003) noted that increases in ventilation rate may be linked to imminent escape response, which is noteworthy in this context due to the high rates of overnight escapes in mahseer subject to combination treatments relative to other treatments. I recommend further research examining the role of escape response in mahseer behaviour.

That condition scores for fish treated to both air exposure and exercise (combination treatment) fell between condition scores for mahseer in air exposure and chase treatments further supports the idea that the physiological effects of these separate stressors may be masked in whole body response measurements such as ventilation rate and reflex impairment indicators. Holding effects are not universal among C&R studies. Taylor et al. (2011) used control trials to anticipate the impact of holding in a post-release mortality study of common snook (*Centropomus undecimalis*) and found no impact of holding. In contrast, Donaldson et al. (2011) noted that net pen recovery resulted in greater physiological impairment to *Oncorhynchus nerka* than study treatments. The modelled outcomes of the condition scores used to account for holding effects in analysis did not show statistically significant differences in condition score among treatment groups or across days though there was a clear trend in the data indicating that condition score worsened from Day 1 to Day 3, and that condition scores were higher (i.e., condition was worse) in treatment groups than in the control group. Condition score measurements aligned closely with those of ventilation rate measurements in that mahseer in the air exposure group demonstrated the clearest trend of worsening condition across days, followed by mahseer in the combination group and chase group, respectively. This result suggests that the compounded results of this multiple capture study (impairment and holding effects) can be viewed as a conservative measurement of actual potential impairment arising from multiple capture events. Additionally, these results suggest that fishes subjected to different stressors may respond differentially to holding, and in particular that mahseer exposed to air may respond more poorly to holding than to those exposed to exercise alone.

Findings in studies examining cumulative and interactive effects of combined stressors have described varied comparative, additive, and multiplicative processes. For example, zooplankton subjected to changing temperatures, toxin levels, and food availability responded in different ways such that combined stressors responses followed neither the comparative nor additive or multiplicative models universally, but tended to favour antagonistic (i.e., stressors worked in opposing directions in an additive manner) or multiplicatively antagonistic outcomes (i.e., stressors worked in opposing directions such that effects were multiplied; Folt et al. 1999). Meta-analysis by Crain et al. (2008) described overall interactions among two or more stressors in marine ecological communities as typically synergistic (i.e., combined stressors result in more severe responses than single stressors), but noted that additive and antagonistic effects were also common. While several studies have examined interactive effects among C&R-induced stressors and water temperature in fishes inhabiting temperate waters (e.g., Gingerich et al. 2007; Gale et al. 2014), few have examined interactive effects among C&R stressors themselves, and even fewer of these studies occur in tropical or subtropical freshwaters or examine the issue of multiple capture. White et al. (2008) examined combined effects of air exposure and exercise in *Micropterus salmoides* and *M. dolomieu* (temperate water species), but did not observe significant impacts of both stressors in a single species and concluded that the two stressors were acting in a separate manner. Studies in subtropical and tropical waters have found similar negative effects of air exposure and exercise on post-release mortality to studies examining the same effects in temperate freshwater species (e.g., on *Salmelinus brasiliensis*, Gagne et al. 2016) and even compared the likelihood of mortality relative to stressor combination and duration (e.g., *Cichla ocellaris*, Bower et al. 2016b), but no known studies have examined the interactions among these stressors in multiple capture scenarios. Similarly, most multiple capture studies occur using mark-recapture methodologies over a longer time period (i.e., years), though some recaptures occur within short time frames also (e.g., in a day; Cline et al. 2012). To my knowledge, this is the only study examining multiple capture within such a short time period (i.e., multiple captures over a three days), but this issue is increasing in importance in high volume C&R fisheries, such as the white sturgeon (*Acipenser transmontanus*) fishery on the Fraser River (e.g., see McLean et al. 2016).

A confounding finding in this study was the prevalence of irregular operculum beats as a sign of minor impairment in mahseer. In previous studies, irregular operculum beats were almost universally a sign of extreme impairment (Bower et al. 2016a; Bower et al. In Review), leading to recommendations that anglers could use impairment of this reflex as an indication that mahseer were likely to be highly impaired and require assisted recovery. In this study, irregularity of operculum beats was the reflex found to be most commonly impaired across all three treatment days.

Conclusion

The findings of my study indicate blue-finned mahseer are unlikely to experience significant physiological effects through multiple capture events, though they are likely to experience temporary and opposing ventilation rate responses as a result of exercise and air exposure. This finding supports the call for improved operational definitions for the combined effects of multiple stressors (Folt et al. 1999; Crain et al. 2008) such that antagonistic, cumulative, synergistic interactions, and other modes of interaction may be accounted for in the responses of fishes to C&R. I urge further research for improved understanding of the manner in which these stressors interact, particularly those in tropical, freshwater environments.

Chapter 7. Angler perceptions and expert knowledge of the Cauvery River mahseer (*Tor khudree*) catch-and-release recreational fishery in Karnataka, India

Abstract

Increasingly, recreational fisheries are being recognized as coupled social-ecological systems wherein angler perspectives, behaviour and management systems play an essential role in recreational fishery sustainability. However, social components of recreational fisheries are rarely studied, particularly during the initial assessment phase, which would provide opportunities for pro-active management of conflict or sustainability issues. In a study of the mahseer catch-and-release (C&R) recreational fishery of the Cauvery River, India, I used online surveys to identify key angler behaviours and perspectives surrounding information gathering, fishing activity, and recreational fisheries management. Respondent anglers reported high amounts of trust in C&R information provided by fellow anglers, family, and friends, and turned to the internet, television, and books less often and with less trust. Anglers also described photo-taking behaviours that suggest lengthy air exposure is a behavioural issue in this fishery. Respondents indicated they strongly supported mahseer and river conservation, but felt low levels of engagement with management organizations. Next, I used semi-structured interviews of recreational fishery experts to place angler perspectives and behaviours into a broader fishery context. Expert interviewees described the relationships among the different actors responsible for managing the mahseer recreational fishery on the Cauvery River, and discussed the role social pressures play in promoting catch-and-release behaviour. The results suggest opportunities are available to improve communication among management organizations, and to improve or build on existing relationships between management organizations and the broader community. Additionally, social sanctions may be more effective than enforcement in supporting the

development of best practices in mahseer C&R, however, such best practices will need to be disseminated at ground level among the angling community. Collectively, the results of this study act as a roadmap to support sustainable management of the mahseer C&R recreational fishery of the Cauvery River by identifying crucial fishery system linkages, and may act as a reference for ongoing development of the fishery throughout South India. I recommended strengthening the links between operating management organizations and the broader angling community, between the research community and the angling community, and the links between the angling community and surrounding communities to promote community and conservation benefit and avoid conflict.

Introduction

Human dimensions research is recognized as an essential component of recreational fisheries research and management (FAO 2012; Hunt et al. 2013; Barnett et al. 2015; Arlinghaus et al. 2016). Improved understanding of human behaviour and fishing activity helps to better explain and predict fishery outcomes (Johnston et al. 2010). Studies of angler perspectives and behaviour are not novel and can be adapted to answer many different questions (e.g., nuances in angler motivation, Fedler and Ditton 1994; choice models to compare management scenarios, Aas et al. 2000; angler conservation values, Dorow et al. 2009; data-gathering via angler apps Venturelli et al. 2017). Yet, the associated findings are not systematically applied to management decisions (Hunt et al. 2013), nor are they commonly applied to recreational fishery assessments (Aas 2002), despite awareness that assessing the social and economic importance of recreational fisheries is considered the first step in sustainable management of the sector (Welcomme 2001). Indeed, major outcomes of the 7th World Recreational Fisheries Conference (Brazil, 2014) acknowledged the need to improve monitoring and assessment for recreational fisheries (particularly those in developing countries and emerging economies) from an interdisciplinary perspective (Arlinghaus et al. 2016) such that the variations in angler motivations and behaviour can be better understood.

Systems-level study has been advised for recreational fisheries also (Arlinghaus et al. 2017). Treating recreational fisheries as a social-ecological system (SES; Arlinghaus et al. 2017) can provide a number of advantages including identifying, understanding, and predicting linkages among fishery system components and fishery outcomes (Ward et al. 2016, Arlinghaus et al. 2017) and incorporating issues of equity and access into fisheries research and management (FAO 2012). Another overlooked component of fisheries research is the incorporation of local expert knowledge (St. Martin et al. 2007; Silvano and Valbo-Jørgensen 2008). Local experts are widely recognized as a source of highly valuable information (Berkes et al. 2016), but this information may be underused owing to difficulties involved in translating the knowledge gathered into data considered viable from natural science perspectives (Silvano and Valbo-Jørgensen 2008; Berkes et al. 2016). Local expert knowledge can help researchers pinpoint crucial areas for further study and provide essential context to foster understanding of local systems, particularly in data-poor situations (Beaudreau and Levin 2014). While it is not possible to adequately approach an unstudied recreational fishery from a SES perspective during the initial assessment phase (without knowing system components *a priori*), it is possible to lay the groundwork for ongoing SES study of the fishery by including human dimensions as an integral part of the assessment phase and designing studies such that key components, issues, and drivers are identified.

The mahseer C&R recreational fishery of the Cauvery River in Karnataka, India is an example of a fishery that would benefit greatly from a SES research approach. Seven species of mahseer have been identified in India (IUCN 2017), though the taxonomic relationships of the genus is still under debate and formal identification of additional species is ongoing. All species of mahseer are believed to be threatened by habitat alteration associated with agricultural pollution inputs (e.g., pollution) and hydropower development (e.g., changes in flows and reductions in connectivity; Everard and Kataria 2011). *Tor khudree*, known as blue-finned mahseer, is believed to occur naturally in several river systems throughout southern India (Raghavan 2011), however, it is unknown whether native populations existed in the Cauvery River (Pinder et al. 2015). The species is listed on the IUCN Red List as ‘Endangered’ (Raghavan 2011).

In the state of Karnataka, there is no official body designated specifically for the management of recreational fisheries. As such, it is possible for organizations to apply to the Karnataka Fisheries Department (KFD) to take over recreational fisheries management in stretches of river through a leasing system (Sugunan 2010). In the Coorg district, the Coorg Wildlife Society (CWS) manages a 28 km stretch of river from Siddapur to the Nisargadhama Forest Reserve (Sehgal 1999). The Wildlife Association of South India (WASI), based in Bangalore, leases a 22 km stretch of river that includes two man-made reservoir lakes (WASI Lake and Forbes Sagar) east of, and a stretch west of, the Shivanasamudra Falls (Seghal 1999). Previously, WASI partnered with Jungle Lodges to develop angling camps known as Galibore, Doddamakali, and Bheemeshwari, however these camps were shut down after changes were made to the Wildlife Protection Act of India (1972) that equated catch and release (C&R) angling to baited hunting activities (Gupta et al. 2015; Figure 7.1).

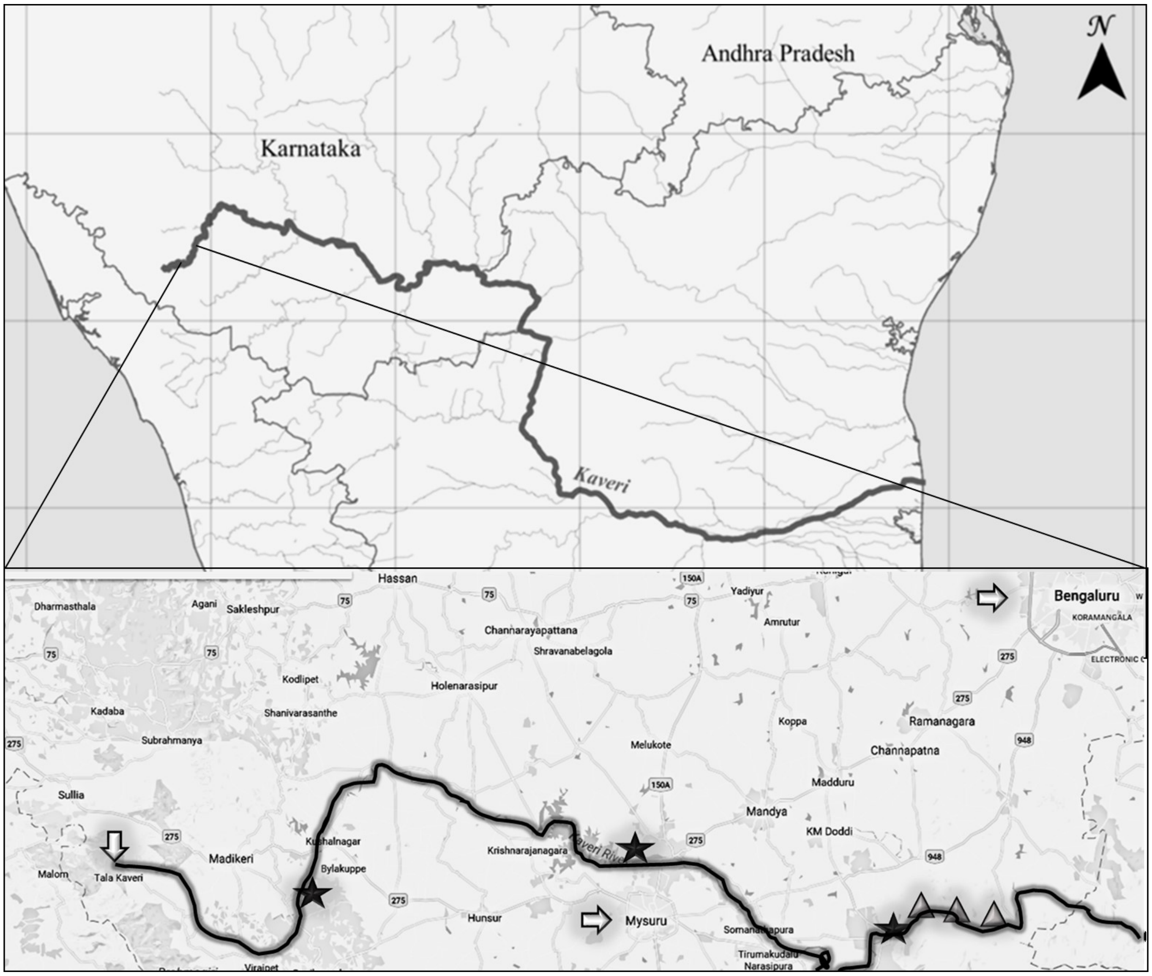

Figure 7.1 The location of the Cauvery River in South India, with important locations in the Cauvery River mahseer catch and release fishery (inset). Areas where mahseer catch and release fishing still occurs (Coorg, KRS Dam, WASI Lakes) are shown in stars from left to right. Major fishing camps that have been closed (Doddamakli, Beemeshwari, Galibore) are indicated by triangles from left to right. Other major locations are indicated by arrows: Tala Kaveri, the source of the Cauvery River; Mysuru, a large city close to all three locations; and Bengaluru, the nearest major city to all angling locations.

Earlier studies have shown that *Tor khudree* are physiologically robust to the process of C&R (Bower et al. 2016; Bower et al. In Review). However, despite the identification of socio-economic considerations as a priority for mahseer conservation (Bower et al. 2017), there was no available information on angler behaviours or preferences regarding mahseer C&R for the Cauvery River, and none of the studies had been placed into a broader cultural- and fishery-specific context. My objective for this study therefore, was to use an SES approach to understand the human dimensions of the mahseer C&R recreational fishery. By characterizing how mahseer anglers perceive their behaviours, and pinpointing the best strategies for engaging with them for sharing findings and best practices, this study can act as a roadmap for predicting angler responses to management activities, such as measured intended to promote sustainability. I also used local expert interviews to place these angler perspectives in the broader management context and understand relationships among the different management entities. This added context offers increased understanding of SES function by predicting the way management bodies will use information and enact rules and regulations.

Methods

Angler Survey

Survey Design and Communication with Respondents

The angler survey (Ethics approval 102791, Carleton University, Canada) was designed to identify behaviours used by mahseer anglers regarding sourcing fishing information, fishing activities (tackle choice and handling processes), as well as identifying angler perspectives regarding conservation activities and recreational fishing management bodies. The angler survey targeted individuals of any skill level that fished recreationally for mahseer on the Cauvery River, and had done so enough times to develop behavioural patterns. The expected population of Cauvery River mahseer anglers is small, with a reasonable estimate for this population of approximately 150 - 200 anglers. Due to the focus on typical behaviours, the survey very likely demonstrates the perspectives of avid anglers, thus avidity bias should be considered (Salz and Loomis 2005). However, as comparing levels of avidity was not a focus of the study, and as the survey was not used to generate estimates of effort or economic value (e.g., Thomson 1991), avidity effects are likely to be minor. Results describing typical behaviours should thus be considered an optimum scenario; for example, less avid anglers may be less knowledgeable of recreational fishing regulations or best practices.

Survey questions took two forms: questions asking for perspectives were formulated using a six-point Likert-type agreement scale, which included a neutral option and an opportunity to choose 'I don't know'. Questions regarding angler behaviour allowed for multiple responses from a supplied list, and included options for anglers to supply their own choices, i.e., 'Other', accompanied by a description. Questions asking anglers to describe sources of fishing information also chose from a supplied list, but were asked to rate their trust in each information source using a five-point Likert-type agreement scale ('Trust completely' to 'Don't trust at all') which included a neutral option ('Neither trust nor mistrust').

Cauvery River anglers typically share English as a common language, so the survey was offered in English. All questions were presented in a closed-ended format to avoid misinterpretation arising from cultural differences in language use. The survey was conducted online through Fluid Surveys (http://fluidsurveys.com/, now Survey Monkey), and anglers were invited via online forums such as the All India Game Fishing Association, and CWS and WASI websites. The survey was launched in February of 2015 and remained available until August 2016. Bi-weekly reminders were issued online for the first six months of the survey, and monthly thereafter.

Survey Data Management and Analysis

Descriptive statistics were generated for respondent demographics and all Likert-type questions. To compare responses among angler groups, responses were separated and categorized according to angler years of experience (collated into fewer than 15 years of experience and more than 15 years of experience due to response types; see demographics, below), and reported expertise (intermediate, expert). Only three anglers self-identified as beginners, and so were excluded from the analysis, along with the four anglers who preferred not to describe their level of expertise. Responses of these groups were then compared to each other according to 'access and trust of information' (questions 4, 5, 6, 7) and angling behaviours (questions 8, 9, 10, 11, 13, 15) using Mann Whitney Wilcoxon tests in R (version 3.3.3, © 2016, The R Foundation for Statistical Computing, Vienna, Austria). The questions included in this portion of the analysis each represent those that could reasonably be treated as interval data (assuming equal intervals, Ziberna et al. 2004).

Expert Interviews

Interview Design and Sampling Methods

In addition to angler surveys, I conducted interviews of individuals whose work or volunteerism had resulted in substantial contributions to mahseer recreational fishery management (Ethics approval 102791, Carleton University, Canada). These individuals were selected via snowball sampling, such that each interviewee recommended other individuals and I continued with interviews until I had spoken to everyone recommended as an expert.

Semi-structured interviews consisting of 27 questions (Appendix ii) were conducted to explore expert opinion on: the relationships among organizations responsible for managing the mahseer recreational fishery, the strategies and policies in place to manage the fishery, the nature of community engagement with mahseer recreational fishing, angler knowledge and compliance with recreational fishing regulations, and the value of recreational fisheries research. No interviewees ended the interview prematurely. Interviews were conducted in person, and took place from June to August, 2016 in Coorg, WASI Lakes, KRS Dam, and Bangalore. One interview was conducted remotely via Skype.

Interview Data Management and Analysis

Interview responses were transcribed and coded for response type (positive, negative, neutral) and by theme during content analysis following procedures described by Neuendorf (2017). Due to the anonymity requirement of the ethical clearance process, external validation of the coding process was inadvisable. Thus, to enhance anonymity during analysis, interviews were transcribed, and transcribed responses were binned per question such that no responses could be associated with individual interviewees by the interviewer. Responses pertaining to a specific topic were then identified as being positive, negative, or neutral on one or more levels. For example, a question asking about the value of research to organization activities could be positive on the first level (research is valuable to organization activities), but negative on a second level (but our organization doesn't make effective use of research). Finally, the semi-structured nature of the interview process allowed for interviewees to discuss additional topics or digress in their responses. Questions where examples or additional commentary were provided were additionally coded for thematic content and are presented in the results by theme (as recommended in Weston et al. 2001). Representative quotes are provided for each response type and coded theme.

Results

Angler Survey

Demographics

Of the 70 survey responses submitted as completed, 39 were deemed usable, suggesting an estimated response rate of 19.5% – 26% (if the true Cauvery River angler population is 150 – 200 anglers). The remaining surveys were unusable due to either multiple submissions or submissions containing only demographic information. Respondents to the angler survey were 90% male (7% female, 3% elected not to identify sex), and most commonly between the ages of 25 – 35 (43%; 45 years – 60 years: 23%; 34 years – 45 years: 17%; under 25 years: 10%, over 60 years: 3%). Half of the respondents indicated they had been fishing for at least 15 years (50%). The remaining respondents claimed 1-5 years (27%), 10-15 years (17%), and 5-10 years (7%) of fishing experience. Most respondents felt that their expertise was best described as intermediate (47%), though 30% described themselves as experts and 10% described themselves as beginners. A further 13% of anglers preferred not to rate their fishing expertise. When asked where they had learned to fish, 45% described being taught by friends, and family (42%), while 35% of respondents indicated they were self-taught, and 4% learned through professional instruction.

Only 30% of respondents chose to answer the question asking about preferred location. Of the respondents that did answer, Coorg and WASI Lakes each appeared in 30% of responses, Mysore appeared in 20% of responses, and Kanapura and Manjeera each appeared once. A single respondent noted that they had turned to fishing for other species (than mahseer) since the Galibore stretch of the Cauvery was closed to angling.

Fishing Information

Respondents described a strong willingness to seek out information on recreational fishing techniques, with 73% frequently seeking out information, and 23% sometimes seeking out information. Only 3% of respondents indicated they didn't seek out any information on recreational fishing techniques. When asked about preferred information sources, respondents were most likely to seek out information from fishing partners (100% very important or important) and family or friends (93% very important or important; Figure 7.3). TV was considered the least important source of information, with 36% of respondents describing it as unimportant or very unimportant, and 46% of respondents noting they didn't use TV as an information source for recreational fishing at all (Figure 7.3).

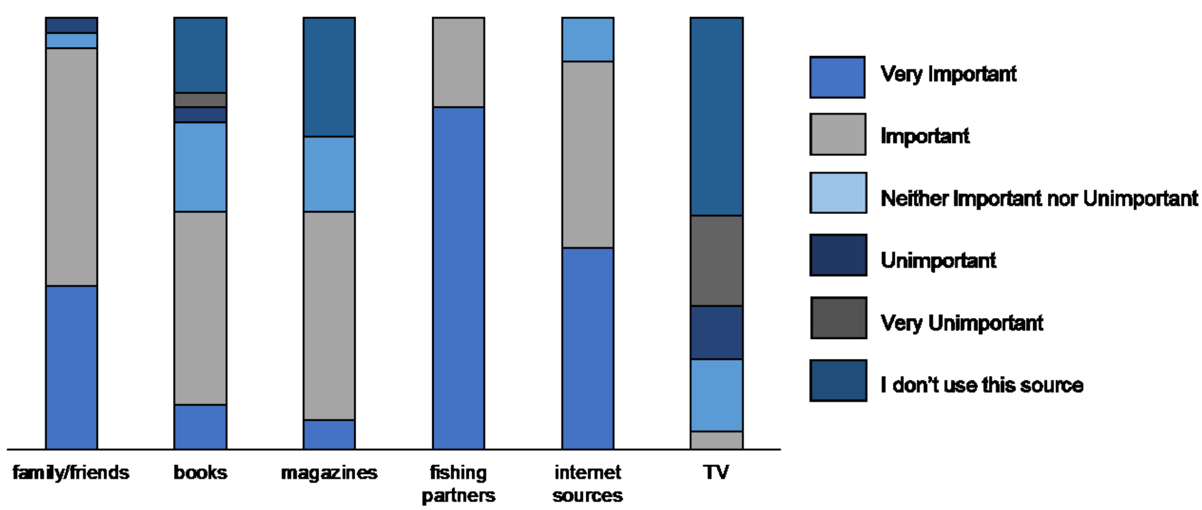

Figure 7.2 Respondents ranked their perspectives on the importance of different sources of fishing information on a 5-point scale ranging from very important to very unimportant, with a sixth option to choose 'I don't use this source' (shown in legend). Fishing partners and family/friends were the most important sources of information, followed by the internet.

Respondents were also asked to describe the degree to which they felt that the information they were receiving on recreational fishing could be trusted to be correct. The preferred sources of information were also reported to be the most trustworthy: fishing partners were trusted completely or somewhat by 97% of respondents, while family and friends were trusted completely or somewhat by 93% of respondents (Figure 7.4). TV was the considered the least trustworthy source of information, with 10% of respondents indicating they either somewhat or completely distrusted the information provided by TV.

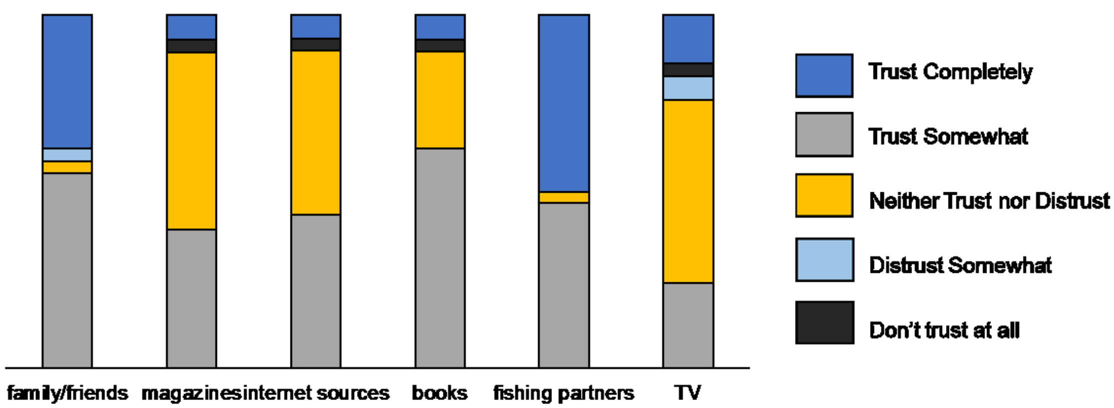

Figure 7.3 Respondents ranked the degree of trust they play in different sources of fishing information on a 5-point scale ranging from 'trust completely' to 'don't trust at all' (shown in legend). Family/friends and fishing partners and were considered the most trustworthy sources of information, followed by books.

Respondents described the circumstances under which they believed they were likely to change their angling techniques based on new information. This question allowed for multiple responses (i.e., asked anglers to 'check all that apply', mean N of responses = 3.1, mode = 2; Table 7.1). Anglers indicated they were more likely to change their angling behaviour if they could judge its value for themselves (try the advice and find it works [26%]; already agree with the advice [20%]), but also indicated high willingness to change behaviours if suggested by a trusted source (expert angler [19%]; other trusted source [19%]).

Table 7.1 Anglers chose among supplied suggestions to indicate the circumstances under which they would be likely to change their angling behaviour. Examples of responses supplied when angler chose 'Other' are shown in the bottommost row.

Which of the following statements describe circumstances in which you are more likely to permanently alter your angling behaviour based on advice from an outside source?	
Question option	**% responses**
I change my fishing practices when I agree with the advice that I'm given	**0.20**
I change my fishing practices when I've tried out the advice and it proves to be sound	**0.26**
I change my fishing practices when a source I trust suggests it	**0.19**
I change my fishing practices when the fish I catch don't recover well	**0.13**
I change my fishing practices when I receive advice from an expert angler	**0.19**
I have never changed my fishing practices	**0.01**
***Other**: "I may decide to not change my practices even after receiving advice from an expert", "Own experimentation…", "I change when there is a decline of a certain species", "Anything that suits the condition"*	**0.02**

Fishing Behaviour and Conservation Perspectives

Responses to questions asking about species preferences when fishing showed 50% of respondents preferred mahseer fishing, but were willing to fish for other species, while 11% of respondents preferred to fish for other species, but would sometimes target mahseer. Despite the question being framed as requiring a single response, many anglers (39% of respondents) chose multiple responses to include 'I will fish for anything I can catch'. Anglers also described a variety of approaches to their fishing activities, with almost half (43%) indicating that they fish very differently for each type of fish they target, and 41% indicating that they fish slightly or very differently for mahseer than for other species.

Asked about the methods they employ to catch mahseer, respondents chose ragi (finger millet paste) on barbed, single hooks as the most frequently used bait (frequently: 29%, very frequently: 29%), followed by lures with barbed treble hooks (frequently: 32%, very frequently: 21%), and lures with barbed single hooks (frequently: 31%, very frequently: 12%). Barbless hooks in any category were the least likely tackle to be used (live bait: never, 60%, ragi: never, 30%, lures: never [treble hooks, 30%; single hooks, 41%]). Almost all anglers (94%) described releasing all mahseer caught back into the water.

Respondents were asked to describe their handling practices regarding photo-taking activity once a mahseer was landed. Just over half (51%) of anglers responded that they took photos of most, or all the mahseer that they caught, with 42% responding that they took photos of some of the mahseer that they caught. Respondents also described the methods they used to take photos of mahseer after landing (Table 7.2). Almost half of respondent anglers (44%) lifted mahseer out of the water, while 24% described leaving them in the water during photo-taking. An additional 20% of anglers described weighing their fish after taking pictures, and 4%

described lifting mahseer out of the water by the gills (Table 7.2). I asked anglers to indicate which attributes of the angling experience motivated them to take photos. Photos primarily served as a reminder of the experience (25%) and showcased big mahseer (23%), though several additional reasons were also supplied by respondents in the 'Other' category (Table 7.3).

Table 7.2 Anglers chose among supplied suggestions to indicate the methods used to take photos of mahseer they caught. Examples of responses supplied when angler chose 'Other' are shown in the bottommost row.

Which of the following statements describe how you take photos of mahseer?	
Question option	**% responses**
I keep the mahseer in the water when I take photos	**0.24**
I lift the mahseer out of the water, holding them by the tail and supporting the body	**0.40**
I lift the mahseer out of the water when I take photos, holding them by the gills	**0.04**
I lift the mahseer out of the water when I take photos, holding them by a stringer	**0.00**
I weigh the mahseer I catch, prior to or after taking photos	**0.20**
None of these statements apply to me	**0.02**
Other: *"I try to lift them from the water for a single photo but support them beneath the body only so they can flip into the water hopefully back into the landing net if they want", "It is better to take a photo of a Mahseer by holding it over soft grass and as low to the ground as possible"*	**0.09**

Table 7.3 Anglers chose among supplied suggestions to indicate the reasons behind the decision to take photos of mahseer. Examples of responses supplied when angler chose 'Other' are shown in the bottommost row.

Which of the following statements best describe why you take photos of mahseer?	
Question option	**% responses**
I take photos when I catch big mahseer	**0.23**
I take photos when I catch mahseer that look robust/healthy	**0.18**
I take photos when I catch mahseer that put up a good fight	**0.10**
I take photos when I catch mahseer to remind me of the experience	**0.25**
I take photos when I catch mahseer so I can show other people	**0.10**
None of these statements apply to me	**0.04**
Other: *"When I use a different technique", "Even when there is any type of abnormality difference or an injury", "…we can understand the changes and can use it to help the species", "I take photos when I catch a mahseer that is different from the ones that I have caught before"*	**0.10**

Respondents reacted positively to questions asking about their support for conservation projects on the Cauvery River, with 79% of anglers strongly or somewhat supporting Cauvery River conservation projects (6% somewhat or strongly opposed), and 90% of anglers strongly or somewhat supporting mahseer conservation projects (0 somewhat or strongly opposed).

Attitudes Towards Management Decisions

Respondents felt management decisions strongly influenced their fishing practices (62%; some impact: 14%; no impact: 24%), but did not indicate strongly negative or positive reactions to management decisions. When asked how they perceived the quality of management decisions, respondents indicated decisions were of neither high quality nor low quality (40%), while 20% of respondents indicated the felt management decisions were of high quality (responses of 'very high quality', 'low quality', 'very low quality' were each chosen by 10% of respondents). Asked to describe the value placed by management on angler input, most respondents suggested that their input was valued (always valued: 25%, sometimes valued: 29%), though a further 29% of anglers indicated that they had no input to contribute to management decisions. These results were somewhat contrasted by responses to the questions of whether current management regulations for mahseer recreational fishing in the Cauvery River were reasonable, to which 50% of respondents answered 'no' (yes: 25%, neither reasonable nor unreasonable: 14%).

Comparison of responses by angler age, years of fishing, reported experience level

There were no notable trends or significant differences in responses between anglers with more or fewer years of fishing experience (< 15 years of experience, > 15 years of experience), nor between anglers who self-reported their skill level as intermediate or expert. One notable (but not significant) difference did occur when anglers were asked to describe the importance of sources of fishing information. Expert anglers were slightly less likely to value information provided by people they fished with, though they still valued this source of information highly (expert anglers: mean = 1.40; intermediate anglers: mean = 1.07; $W = 93$, $p = 0.06$).

Expert Interviews

Due to the small size of the Cauvery River mahseer fishery, the pool of recognized experts is small (N = 10). Of the invited interviewees, one person declined to be interviewed. Most interviewees (N = 6) were members of or associated with one or more of two management organizations: WASI (4 interviewees), and CWS (3 interviewees) Three individuals were not formally associated with, or members of, any of these organizations, but had relevant background experience and expertise regarding all the relevant organizations. Interviewees had spent an average of 9.5 years associated with these organizations (range: 2 years – 35 years, median: 6 years).

Organization Roles and Relationships in Managing the Mahseer Recreational Fishery

When asked to describe which organizations played a role in managing the mahseer recreational fishery on the Cauvery River, interviewees identified several organizations and groups of people, including WASI, CWS, the Karnataka Fisheries Department (KFD), local panchayats (council groups of respected villagers), and Jungle Lodges. It was agreed by all but one interviewee that both WASI and CWS currently played the most active roles in designating rules and regulations for recreational fishing of mahseer and in enforcing those rules. The most important regulations on the WASI stretch were described as ‘mandatory C&R of mahseer’ and ‘mandatory removal of invasive species’. The most important regulations on the CWS stretch were described as ‘mandatory C&R of mahseer’, ‘no fishing of any kind in the sanctuary’, and ‘no fishing from a coracle’. Three interviewees (33%) mentioned that local panchayats were often consulted for decision-making, and helped to communicate CWS management decisions (of all kinds) to local village and tribal groups. Three interviewees (33%) also considered that the former role of Jungle Lodges in managing angling camps and promoting a C&R ethic was valuable to current management efforts. There were somewhat conflicting perspectives on the role of the KFD in supporting management of the fishery, with 44% of interviewees describing the KFD role as negligible, and 33% interviewees describing the KFD role as essential (22% of interviewees did not address the role of the KFD).

While interviewees agreed that the two major management entities, WASI and CWS did not have actively cooperative relationships, two interviewees noted that both organizations shared members and positive relationships were described between the KFD and CWS. Another interviewee noted that the two organizations shared common goals and had collaborated on some projects involving mahseer (Table 7.4).

Table 7.4 Representative quotes describing interviewee perspectives on relationships between the organizations responsible for managing the mahseer C&R recreational fisheries of the Cauvery River. Text not in italics represents clarification, but is not part of the direct quote.

How would you describe the way the organizations managing the mahseer C&R fishery on the Cauvery River relate to one another?
Representative Quotes (positive)
"KFD and CWS are involved quite a lot. We approach them for anything, everything. We keep them updated on all our projects, meetings, and analysis. They are a part of everything we do. WASI, not very much really. We are aware of each other. Lately, we have mahseer projects in common, and we both try to get as much information across as possible."
Representative Quotes (neutral)
"WASI is connected with Jungle Lodges in a certain way, and WASI does relate with government organizations in the area, and (with) forest officers. CWS is related to WASI in the sense that some members are part of both organizations, but not active relationships in terms of thinking on a common platform. There are both positive and negative relationships, depending on who's at the helm."
Representative Quotes (negative)
"None (no relationship between WASI and CWS). *When they barred fishing at the camps, the Cauvery fishery just basically shut down."*

Interviewees were asked to comment on the role personal relationships played in management decisions concerning recreational fishing on the Cauvery River (Table 7.5). Most interviewees felt personal relationships played a strong role in the decision-making process of the management organizations responsible for mahseer recreational fishing (strong agreement or agreement: 77%, neutral or noncommittal: 22%). Responses indicating agreement were characterized in two distinct ways. Some interviewees (33%) viewed the role of personal relationships in decision-making as a positive attribute of the decision-making process. These included interviewees who felt personal relationships could play a positive role in decision-making processes but felt these relationships were not being used effectively. Interviewees who felt that personal relationships played a negative role in management decisions concerning mahseer or recreational fishing on the Cauvery River (44%) described situations wherein personal relationships overpowered decision-making processes. Interviewees who were non-committal or neutral regarding the role personal relationships played in decision-making processes acknowledged both positive and negative aspects of the issue, and the challenges inherent in running an organization responsible for making management decisions.

Table 7.5 Representative quotes describing interviewee perspectives on the role personal relationships play in management decisions concerning mahseer or C&R recreational fishing on the Cauvery River. Text not in italics represents clarification, but is not part of the direct quote.

How would you describe the degree to which personal relationships play a role in decision-making in the mahseer C&R fishery?
Representative Quotes (positive)
"Personal relationships are the thing that matters. If people don't want to respect the rules, they'll respect the person (making them)*... People listening to fish rules had more to do with respect for the founders than for respect for the rules."*
Representative Quotes (positive setting, negative outcome)
"I feel that the guys who have been with the organizations a long time know everyone- everyone at the fisheries department, at the forest department- and they could have a really good impact, but they don't use it."
Representative Quotes (neutral)
"Every organization has a body of people from its members who are elected to be the office bearers; they are the decision makers for that organization… The individual member of any organization can play an active or passive role. They can highlight any issue that pertains to the organizations and raise it. It's difficult to say how many play an active role and how many don't, but it's probably fair to say that in any organization there will be a core group of members who do play an active role."
Representative Quotes (negative)
"The problem with these organizations (despite having good intentions) is that they are traditionally old anglers who have been there, done that. So, they sit at the head of the table and don't want to change anything. What we need are younger members to take part and replace these bodies so that decision-making is faster and data-driven, rather than personality-driven. Right now, it's personality-driven."

Angler Compliance

Interviewees offered their perspectives on how anglers viewed and complied with angling regulations in both managed stretches of the Cauvery River. There was no clear consensus on whether anglers were likely to follow rules, with some interviewees believing anglers readily complied with regulations (22%), some believing anglers sometimes complied with regulations (framed as either more likely or less likely; 55%), and others believing anglers rarely complied with regulations (22%). A source of this disagreement was the nature of angler orientation: those interviewees who felt anglers only sometimes or rarely complied with angling regulations described different angler types according to their support of C&R (Table 7.6). Interviewees who believed anglers were likely to readily comply with regulations noted that anglers may not agree with all regulations (e.g., lack of access to fishing in sanctuary spaces), but would follow the regulations regardless.

Table 7.6 Interviewees identified conflicting angler orientations that influence compliance with recreational fishing regulations on the Cauvery River, India, and described those conflicts using three themes: descriptions of compliance wherein respect for regulations is paramount, situations wherein social pressures dictate success, and situations wherein angler motivation dictates success.

Themes	Anglers More Likely to Comply	Anglers Less Likely to Comply
Regulation Respect Paramount	*"Anglers are ok with all of these rules but the sanctuary one, since that's were all the big fish are."* *"(Anglers are) not very happy, I'd say, but again, they've been used to a certain set up, so when you tell them rules have changed, some will still come back, but some won't."*	*"I would imagine every angler releases mahseer; removal of invasive species, they'll be more than happy to take them out; as far as the bag limit, it's a contentious issue but whether people strictly follow it is debatable."*
Social Pressures Dictate Regulation Success	*"The catch-and-release as a concept is very new, and I think education is very, very important. But we also need to take baby steps. The first one is catch-and-release, the next one is handling. Many anglers who currently practice catch and release only do so because of pressure. Beyond these individuals though, many and more anglers support catch and release and best practices. And it's growing*	*"Most of them follow the rules, but I do hear stories, like saying they've released them but don't."* *"Those who are anti- catch and release will probably stick to the guideline of releasing mahseer but keep other species. They will probably also preferentially target those species they can harvest. Once outside of (organization) boundaries,*

	really quickly. I think we'll see a lot of positive change in the coming years."	*they will take whatever they want from the water."*
Angler Motivation Dictates Success	*"(There are) two lots of people: people who do catch and release, and people who don't understand it at all. The second group want to get their money's worth."*	*"No, anglers don't follow the rules. Though they catch-and-release, if they don't catch enough fish, they still take fish away, even if it's mahseer."*
	"There are people who are very conscious about mahseer. They might not have the handling skills, but they try. There are still others though who are just there to see how many fish they can take back."	*"Nobody follows rules! Everyone's always after as many fish as they can, or sometimes big fish…It's just the obsession with getting THAT fish, and they want to do whatever it takes and so don't always understand or follow the rules."*

Community Benefit

Interviewees described the relationships between management organizations and local communities in terms of both benefit and awareness. Interviewees felt that members of the local community benefited from mahseer recreational fishing activities in terms of direct economic benefit (whether minor or significant, 33%), via indirect ecological benefit (33%), or that the community did not receive any tangible benefits whatsoever (33%; Table 7.7). Two interviewees who believed that the local communities benefited indirectly from recreational fishing activities disagreed about whether members of the local community were aware of these benefits.

Table 7.7 Representative quotes describing interviewee perspectives on the views of the local communities regarding the mahseer C&R recreational fisheries of the Cauvery River, according to interviewee depictions of benefits being direct, indirect or intangible. Text not in italics represents clarification, but is not part of the direct quote.

Direct Economic Benefit	*"All of the poachers got hired by all of these camps, and as a result could educate their children, feed their families, and even build new homes… the tips they got were about triple their salaries. Once this was taken away from them there was nothing else to do but go back to poaching."*
Indirect Ecological Benefit	*"If they* (local communities) *do, they're not aware of it. I mean, the river is nice and clean, which means the fishing has to be good, the ecology has to be good, but they're not aware of it necessarily as a benefit."* (Unaware) *"They* (local communities) *do, particularly when you're dealing with protected stretches and areas. Because, once the rains come and the protected fish (now bigger and more numbers) move into the main river, they can catch them. The locals realize this."* (Aware)
No Tangible Benefit	*"The locals are not interested in sport fishing, they're into subsistence fishing. Of late, we've been hearing that people aren't interested in taking mahseer home- they don't want to eat it… they don't mind anglers being on the river despite them not benefiting."*

The Value of Research to Management Organizations

All interviewees indicated that research involving the mahseer C&R recreational fishery was of value to their organizations and efforts, but they had several suggestions regarding ways in which this benefit could be improved. Improved communication of research findings was a primary focus of these suggestions (77%), including short reports to management organizations and media releases that avoid complex terms or jargon; improved communication with organizations and anglers throughout the research process and on an ongoing basis; and, working collaboratively (not confrontationally) with all river users. Additional research topics suggested during the interviews included expanding research through adopting an ecosystem perspective, conducting assessment work on other river systems, quantifying the impact of destructive fishing methods on fish populations to compare viability of solutions, and finding better ways to incorporate angler and local knowledge into studies.

Visions of the Future

"It's more than just about fish, it's about the health of the river itself."

The interview process closed with a question asking interviewees to offer their thoughts on the future of the mahseer C&R fishery on the Cauvery River. The majority of interviewees offered positive statements about the fishery's future (77%), though most of these were qualified with 'if' statements (44%; Table 7.8). Two interviewees used negative statements when discussing the future of the mahseer recreational fishery (22%; Table 7.8).

Table 7.8 Representative quotes describing interviewee perspectives on the future of the mahseer C&R recreational fishery of the Cauvery River, categorized by outlook as positive, qualified, or negative. Text not in italics represents clarification, but is not part of the direct quote.

Positive Outlook	*"One good thing is that at least in the last couple of years there's been quite a lot of noise being made about mahseer that didn't used to be there. There's also some focus on the waters* (river health). *What we need to do probably is go grassroots to schools and villages and try to make presentations on angling and get more people involved. In India, we have such a huge population and we've barely scratched the surface."* *"As long as there's an angling community, and even if it grows at a very marginal rate, catch and release angling has a future. We need more anglers, more active anglers, and unless we're able to recruit more you may end up with a generation of old anglers who will fade away. But some young anglers are getting more involved, and as long as that happens, there's no danger of catch and release fading away."*
Qualified Outlook	*"If it's* (the fishery) *in a protected stretch of river and well managed, with a lot of guards patrolling and monitoring the river, and the local community benefits from the fishing activity, then the benefits would be fantastic. If not, then, "if you can't beat them, you join them" in terms of breaking rules to catch fish. People wish fish elsewhere and break rules."* *"It all depends on the government and the fisheries department, so it's hard to say, but the NGO's all need to keep doing what they're doing, basically. We need to try and spread out to other places too, not just the Cauvery, but replicate the angling-conservation model elsewhere."*
Negative Outlook	"(In) *ten years time, there won't be any mahseer left, including the blue fin. They'll all be poached. Between the falls and Mekedatu, they're basically landlocked in 47 km of river."*

> *"The blue fin* (stocked species) *will survive, the orange fin* (native species) *has been wiped out, or at least, is very close."*

Additional Topics Covered During Interviews

Poaching:

All but two interviewees (77%) distinguished between 'poaching' and fishing 'for the pot', whereby people who adopted destructive fishing methods (dynamiting, poisoning, etc.) were considered poachers, while people who were catching a fish to take home for food were considered local fishers who had the right to do so. Of the two who didn't agree to this description, one differed only in that they included netting activities (gill netting and cast netting) in the poaching definition. The other dissenting opinion considered any fishing activity that removed mahseer permanently from the water as poaching. A single interviewee offered some nuance to illegal poaching at WASI, noting that: "*There are plenty of other places to fish there, so they* (villagers) *shouldn't fish at Forbes* (Forbes Sagar, one of the two WASI lakes)*, but they do."*

Tor khudree stocking:

All but one interviewee mentioned the stocking of *Tor khudree* in the Cauvery River. There was consensus in the perception that stocking played a role in the decline of the local native species, the humpback mahseer (not yet formally described; see Pinder et al. 2015). One interviewee described the humpback mahseer decline as a culmination of events, suggesting that preferential poaching of large humpbacks during dry seasons (when they are restricted to shallow pools), unusual weather patterns such as failed monsoons, unusually high water temperatures, and the introduction of blue fin all played a role. From this interviewee's perspective, the first two factors cemented the decline of the humpback, and the decline itself allowed for the proliferation of bluefin.

Discussion

The results of this study act as a roadmap to support sustainable management of the mahseer C&R recreational fishery of the Cauvery River by identifying crucial SES linkages, and act as a reference point for ongoing development of the fishery throughout South India. Survey results, when combined with the perspectives provided by local experts, indicate not only which linkages are important to the recreational fishery SES, but where they are strong or weak. Angler survey responses indicating a lack of engagement with management organizations, combined with expert interviewee responses discussing the independent and siloed activities of the organizations suggest that solidifying the link between operating management organizations and the broader angling community could benefit mahseer and riverine conservation efforts. Survey responses describing the nature by which anglers gather trustworthy information on fishing (friends, family and expert anglers) combined with expert interview responses discussing the role personal relationships and social pressures play in encouraging compliance with regulations suggests that the link between the research community and the angling community (whether via management organizations or independently) should also be strengthened, and further indicates that the most effective strategies for knowledge uptake will occur at the community level. Angler survey respondents described high levels of support for conservation activities, particularly those involving mahseer, but expert interviewees described varying and minimal benefits of angling activity to the communities surrounding angling areas, which suggests that building links between the angling community and surrounding communities could serve to promote community and conservation benefit and avoid conflict. I explore these linkages in the remainder of this section and offer recommendations of how they may be used to promote sustainability in the Cauvery River recreational fishery SES.

Optimizing Angler and Management Organization Relationships

The first linkage identified in the mahseer C&R fishery on the Cauvery River is communication between anglers and management organizations, and among management organizations. Angler involvement in management decision-making processes has been shown to improve success of conservation efforts (Granek et al. 2008; Cowx et al. 2010). However, the success of such engagement efforts depends largely on the effectiveness of chosen communication strategies (Dedual et al. 2013). Survey respondents and interviewees noted that they perceived few opportunities to communicate both within and between relevant organizations. A review of case studies examining the barriers to successful communication by Dedual et al. (2013) identified angler concern that management decisions would limit access to fishing areas or opportunities as a critical barrier. Danylchuk and Cooke (2011) noted similar concerns regarding restricted access in a study evaluating angler responses to protected areas. These issues appear relevant to the Cauvery River mahseer fishery, as interviewees reported that anglers were not in favour of a protected area (sanctuary) implemented by CWS. Additionally, the angling ban instituted by India's Supreme Court may also be resulting in negative perception of management organizations and may challenge or strain relationships between the angling community and management organizations. There may be opportunities for both organizations to improve coordination by initiating regular communication, by working together to address access issues along the Cauvery (as instituted by the ban), or by providing increased opportunity for anglers to submit feedback on decision-making processes (which may enhance social capital, Plummer and

Fitzgibbon 2007). There are also opportunities to improve communication and relationships such that the KFD could become more actively involved in recreational fishing activities. Anglers, however, should also be prepared to engage in a similar manner, whether through dialogue with management organizations or by offering support in other ways, as it is the communication process itself that is crucial to positive outcomes (Plummer and Fitzgibbon 2007).

Social Relationships Inform Responsible Angling Practices and Research Communication

The second linkage identified in this study relates to the first in that it directly involves the nature of communication among anglers, such that there is a strong potential role of social sanctions and personal relationships to influence angler behaviour. Peer to peer communication and social sanctions may strongly support adoption of regulations through bottom-up processes (Danylchuk and Cooke 2011; Cooke et al. 2013). Survey respondents reported that the most important sources of information on recreational fishing were fishing partners, family, and friends. These same information sources were also rated the most trustworthy. Respondent anglers also indicated a reasonable degree of awareness regarding responsible angling practices for mahseer, with the majority indicating that they either kept the fish in the water, or lifted it out from the water while supporting the fish with both hands. That presumptive awareness was mitigated however, by additional common behaviours. A quarter of respondents described weighing the fish after photo-taking suggests that time out of water may be significant in this fishery (e.g., many photo-taking and weighing sessions result in several minutes of air exposure, S. Bower, personal observation). Further, expert interviewees described situations wherein C&R behaviour was influenced by social pressure, and wherein respect for authority figures played a large role in voluntary compliance with regulations. These findings combine to suggest that the mahseer C&R fishery may be well-positioned to benefit from angler-led efforts to improve widespread adoption of recommended angling practices and support other conservation-oriented behaviours (commonly led by avid anglers, Cooke et al. 2013) provided recommended practices are communicated effectively.

That social relationships play a strong role in the mahseer C&R fishery presents challenges regarding research processes and communication of research findings. Angler reliance on peers for fishing information means that responsible practices need to be communicated and disseminated at ground level among the angling community (e.g., through collaborative education, Fujitani et al. 2017), particularly in scenarios where organizational authority is less effective (Cooke et al. 2013). Expert interviewees overwhelmingly asked for better communication with and by researchers, which also indicates the value of this type of information delivery, and reinforces the finding that responsible practices need to be communicated actively if uptake of this knowledge is to occur.

Community Benefits and Involvement

Opportunities to improve communication were also relevant to the third established linkage, between the angling community and the riverine communities where angling activities take place. Specifically, proposed solutions identified in the previous sections may be useful in developing stronger relationships between angling and community groups. The lack of broader community involvement in recreational fishing activities was described primarily in terms of indifference by interviewees, but also indicates that improvements could be made to foster social and economic equity through forms of profit sharing (e.g., see sociocultural best practices for ecotourism development, Barnett et al. 2015). Expenditures from angling activities could be shared with the community through preferred access, such as promoting purchasing supplies from local vendors as suggested by one interviewee, or through prioritizing subsistence access to local community members under a process mutually-agreed upon, as enacted by CWS.

Differences in approach to the issue of subsistence fishing were identified during the interview process, where CWS distinguishes clearly between which activities constitute poaching and which constitute fishing ‘for the pot’. The perception regarding subsistence fisheries around WASI Lakes was described as one in which any fishing activity in the lakes by locals is viewed as poaching. The issue of poaching, discussed as a tangent topic by several interviewees is highly complex. Understanding the current positions of the organizations requires understanding that prior to the angling ban, known poachers were hired to act as guides and guards of the managed stretches (Gupta et al. 2015). After the ban, poaching activity is perceived to have increased (Pinder and Raghavan 2013) and poachers are perceived to have honed their craft during their tenure as guides. This issue could itself be an opportunity to involve the community in recreational fishing activities and solve access-driven conflicts surrounding poaching and subsistence activities. This would be of benefit to WASI, as the organization is based in Bangalore and thus need to promote compliance from a distance.

Conclusion

The results of this study identified key linkages in the Cauvery River SES that could be further explored and improved through communication processes to facilitate relationship-building among recreational fishery stakeholders, address ongoing issues of equity and access within the fishery, and support uptake of recommended practices and knowledge sharing within the angling community. Each of these attributes is considered valuable in supporting sustainable management of recreational fisheries (Elmer et al. 2017), but will be of value to this fishery given that the target species are endangered and legal challenges have constrained its growth. Work now needs to be done to understand how these SES components interact, and what feedbacks occur during those interactions to improve predictive capability and foster resilience (Arlinghaus et al. 2013).

In addition to fishery-specific linkages, I recommend incorporating a larger scale focus on recreational fishery management, such that other stakeholder groups and watersheds are included. Perceptions described by survey respondents and interviewees demonstrated fishery-specific perceptions that may challenge this recommendation, however. Both groups referenced issues surrounding stocking practices and endangered species in responses, commonly framed with a negative perception of *T. khudree*, arising from the perceived role of *T. khudree* stocking in the decline of the native humpback (see Pinder et al. 2015). However, there appears to be less awareness that *T. khudree* is also highly endangered in its native range, a range which may or may not include the Cauvery River. Research examining the ecological relationships (historical and current) between these species is ongoing, and outcomes could be highly influential for supporting the continued existence of both species.

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Chapter 8. General Discussion

The overarching objective of this work was to identify linkages in the recreational fishery social-ecological system (SES) most likely to influence sustainable growth and management of the Cauvery River mahseer recreational fishery. The integrated rapid assessment protocol I developed and used in this research met this objective and provided additional information and context through the operationalization of SES approaches for assessing data deficient recreational fisheries. I first explored the nature of data deficiencies (knowledge gaps) in developing world recreational fisheries in Chapter 2. After identifying the mahseer C&R recreational fishery as a suitable case study, I involved local experts and stakeholders in identifying research and conservation priorities most likely to address the research objective within a local context (Chapter 3). I then examined linkages between the angler and resource subsystems by investigating the effects of C&R activities on blue finned mahseer of the Cauvery River (Chapters 4, 5, 6). Finally, I explored connections between the angler and management subsystems through angler surveys and expert interviews in Chapter 7. Collectively, my findings indicate that while angler systems are not likely to significantly affect resource systems in the Cauvery River SES, there are influential connections between angler and relationship subsystems, and weak links between angler and management systems because of information barriers.

Research Findings

Outcomes of Chapter 2 showed that knowledge gaps surrounding developing world recreational fisheries are severe, but also highlighted the growth already occurring in the sector and demonstrated the utility of a multidisciplinary approach to addressing data deficiencies.

Outcomes of Chapter 2 also identified potential positive outcomes of growth in the global recreational fishing sector, namely that the harvest orientation of freshwater and coastal recreational fisheries indicates that the sector can act as a source of additional nutrition (see Cooke et al. In Press for a review of recreational fishing contributions to nutrition; Lynch et al. In Press for relationships between inland fisheries, nutrition and poverty). Additionally, the sector may act as a source of alternative or part-time livelihood to support fishers and local communities (e.g., Pawson et al. 2008; Potts et al. 2009). Of equal note in Chapter 2 was the issue of the role Western-centric views and research play in interpretation of recreational fisheries research outcomes. There is a need to ensure that local knowledge, culture, traditions, and processes are accounted for in global recreational fisheries research such that these differences can be better understood and used to inform a more realistic image of the sector.

The value of a SES approach in understanding local context (as recommended by Steyaert et al. 2007; Reed 2008) was the focal point of Chapter 3, where I met with stakeholders and experts to identify research needs and conservation goals. The severity of data deficiencies in the mahseer recreational fishery were apparent in the outcomes of the workshops, which noted that no research had been conducted on mahseer responses to C&R activities. Relevant priority research items identified in this study included determining the effects of C&R on mahseer, evaluating whether community connections to mahseer can foster conservation-oriented behaviour, developing estimates of economic expenditures generated by recreational angling activities, and evaluating suitable strategies for benefit-sharing with local communities. Results from the subsequent chapters focused strongly on the first priority research item, but also provide insights for the remainder.

When considered holistically, results from Chapters 4, 5, and 6 indicate that *Tor khudree* are physiologically robust to catch and release, however there are some findings in this work that offer important nuance and suggestions for future directions. The findings of the preliminary physiological response assessment (Chapter 4) suggested that blue finned mahseer were significantly more likely to exhibit reflex impairment if exposed to air and exhibit significantly higher blood lactate levels after prolonged periods of angling. Neither finding is surprising on its own, as many fishes demonstrate increased impairment after air exposure (see review by Cook et al. 2015), and blood lactate levels would be expected to correlate with angling time because of increased exercise (Wood et al. 1983; Cooke et al. 2013). However, I noted in the conclusion of Chapter 4 that angling times for blue finned mahseer were typically longer than would be expected in a similar fishery as the fish are anecdotally well known for multiple runs and using structure to avoid capture. Anglers also often use gear that is too light for trophy-sized fish (S. Bower, personal observation). In the telemetry study described in Chapter 5, I did not find the same influence of angling time and air exposure on fish response, even when combined with the external tagging process. I did find, however, that larger fish exhibited a biologically significant, if not statistically significant, trend towards increased movement rates post-release. Increased movement post-release was also found by Thorstad et al. (2004) in a study of cichlids of the Zambezi River, and was similarly interpreted as a sign of impairment. Moreover, in Chapter 6, findings indicated once again that air exposed fish (whether through solely air exposure or in combination with angling processes) were more susceptible to the impacts of holding processes than control fish or fish that were only subjected to chase treatments. Additional findings from Chapter 6 suggested that while instances of multiple capture were not likely to significantly increase the likelihood of post-release mortality (as measured by reflex impairment) temporary impairment (as measured by ventilation rate) was significantly more likely in mahseer subject to air exposure, chase and combination treatments and that these effects were likely to interact.

Taken as a whole, these findings indicate that while effects of C&R may be minor for most blue finned mahseer, individual or cumulative effects can result in negative consequences to individual fish, and are more likely to impact large-bodied individuals. For example, fish subject to multiple stressors such as longer air exposure, angling, or handling times may be more likely to experience negative effects than fish subjected to a single stressor (though the presentation of these effects might vary such that some are masked by antagonistic processes, Folt et al. 1999; Crain et al. 2008). Large mahseer are more likely to experience increased C&R-related effects as they are typically subject to extended angling times and prolonged air exposure, as described in Chapter 7 wherein anglers noted they commonly took photos of large mahseer. I strongly suggest that a crucial next step in evaluating the sustainability of C&R recreational fishing for mahseer would be a study examining the consequences of combined C&R stressors on trophy-sized mahseer. Not only are these fish the most likely to be affected, but they are also the most fecund of the population.

Over the course of this assessment I have heard several anecdotal reports of mahseer behaviour during monsoon season indicating that fecundity is likely to plateau after a certain size (this is reported to occur at approximately 30 kg). Local experts have noted that beyond this size, mahseer do not participate in breeding activities or migration. While this information does not accord with our understanding of typical reproductive behaviour across a breadth of species, it has been reported to me on several occasions. Furthermore, a reduction fecundity has been found in older female sturgeon (Eenennaam and Doroshov 1998), suggesting that similar phenomena in mahseer is a possibility. I believe that a study of the impacts of C&R on trophy-sized mahseer could be combined with a telemetry study that would confirm or refute this local understanding. Were such a change in behaviour according to body size to be found accurate, it would have significant implications for the fisheries management of this species group.

The studies examining the social components of the blue finned mahseer C&R fishery (Chapter 7) offered important findings that put the previous chapters into context. In addition to providing baseline information surrounding typical mahseer C&R practices, results from the angler survey showed that anglers were conservation-oriented and supported C&R regulations (agrees with findings of Gupta et al. 2015), but that common recommended practices surrounding C&R activities were less universally adhered to. For example, there was more variation in responses describing photo-taking practices. The survey results also showed that angling practices in the mahseer C&R fishery did not vary according to reported angling expertise or years of angling experience. This finding was in contrast with other studies, which typically note different behaviours between less experienced and more experienced anglers (e.g., see Meka and McCormick 2004; Johnston et al. 2010).

Equally important to overall social context within the fishery were the findings regarding angler access to and use of information. Anglers reported seeking out information on angling practices on a regular basis, but sought out the information most commonly from fellow anglers, family, and friends. Additionally, anglers described placing a very high amount of trust in the information provided by these sources. This finding suggests that there is a barrier to information transfer occurring at the boundary of the angling community, such that information within the angling community will be shared and readily trusted, but that information outside the angling community will not easy be integrated. The existence of the barrier demonstrates that managers and researchers will have to develop new ways of communicating information and that communication will need to occur at community level.

The local experts who participated in interviews (Chapter 7) placed the outcomes of both the biological and social studies into a broader management context. By describing the lack of interaction among relevant management organizations, the role of personal relationships in management decisions, and the opportunities for improving relationships and benefit-sharing with local communities, interviewees aided the identification of crucial SES linkages that should be strengthened to support sustainable management of the fishery (see Arlinghaus et al 2017). Additionally, interviewees offered insight into relationships between the angling and local communities pertaining to shared benefits and indicated there is a need to increase actual and perceived social equity among these groups.

Findings in the SES Context

As discussed in Chapter 7, it was not possible to fully approach the rapid assessment process from a SES perspective without *a priori* identification of SES linkages and interactions (an essential component of SES study; Hunt et al. 2013; Arlinghaus et al. 2017). However, I maintain that by incorporating human dimensions as part of the initial assessment process I have laid the groundwork for future study and treatment of this fishery using SES models by designing the rapid assessment process such that key linkages and drivers were identified (Figure 8.1).

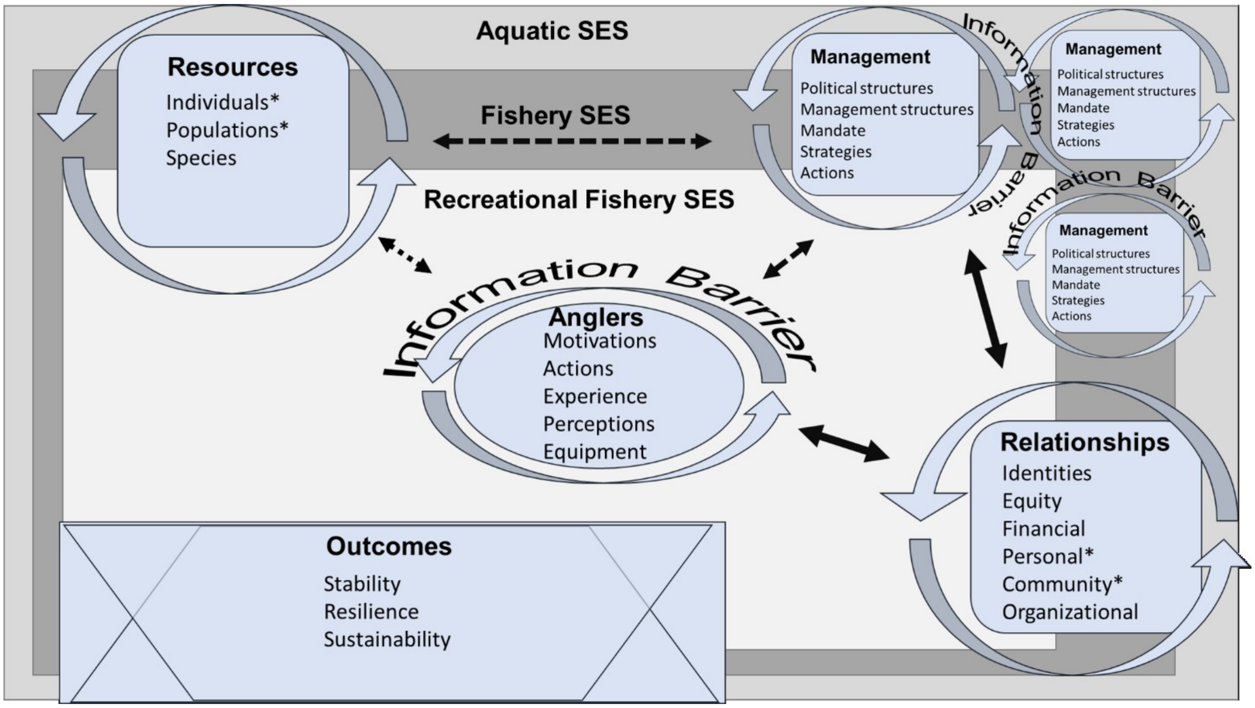

Figure 8.1 A depiction of the Cauvery River mahseer recreational fishery SES as adapted from the figure in the general introduction (Chapter 1, Figure 1.1). Here again, the recreational fishery social ecological system (SES) is nested in the broader fishery sector SES, which includes other harvested fish species and small-scale commercial, subsistence, and indigenous fishing activities. The fishery SES is nested in the broader aquatic ecosystem SES, which includes all other aquatic ecosystem components and other aquatic resource users, such as the agricultural and tourism industries. Embedded shapes (Resource, Management, Relationships) indicate key subcomponents of the recreational fisheries SES that link it via potential routes of action to both nested SES. Note that an important aspect of the management system of the mahseer C&R fishery of the Cauvery River is that the components of the management subsystem are further subdivided into individual components based on organization (KFD, CWS, WASI). Attributes listed in these subsystems that are starred (*) represent those explored in this research. Cyclical arrows around the angler system and related subsystems indicate the ability of all potential interactions to influence and interact with each other, e.g., angler actions that influence the resource system via introduction of invasive species potentially influence fish populations and species, the decline of which can influence the proliferation of invasive species. The arrows connecting the angler system to each subsystem are described in this figure in terms of relative linkage strength. The dotted arrow connecting the angler system to the resource subsystem represents a weak linkage in terms of driver effect, though the linkage is maintained through angler behaviours such as air exposure and invasive species introductions. The dashed arrows (connecting management subsystems to resource subsystem and angler system) represent weak or unrealized linkages, arising from the lack of formal oversight of recreational fishery resources by management bodies and lack of communication between the angling and management groups.

The thick solid arrows (between the relationship subsystems and angler and management subsystems) represents strong linkages that can act as both positive and negative drivers. Also pictured in this figure are information barriers. Information barriers occur among management organizations, which are highly separate from each other, and surrounding the angler system, due to the way information surrounding fishing practices is shared within the angling community. All the potential outcomes (pictured as various shapes in both bottom left) are retained in the mahseer C&R fishery SES, i.e., no possible outcomes can be eliminated as a result of research findings. Outcomes of recreational fishery SES processes may have low (front trapezoid), enhanced (inverted trapezoid), or proportional effects on the broader fishery and aquatic SES.

My findings show that C&R is not likely to act as a strong driver of change in the resource subsystem, but that potential effect linkages remain between the angler and resource subsystems via increased consequences of C&R in large-bodied mahseer, via unstudied interactions among cumulative effects of C&R, and via angler behaviours such as prolonged air exposure for photos and reported intentional introduction of invasive species. Conversely, there is a very strong link between the angler and relationship subsystems in that anglers are strongly believed to follow C&R rules for mahseer based on their relationships (membership in) organizations, and the large amounts of trust placed in family and friends. This strong link be both a positive driver and a negative driver; for example, the strength of relationships can encourage social sanctioning that promotes responsible angling practices, but can also perpetuate irresponsible practices. I found a similarly strong link between relationship and management subsystems that can act in the same manner: as described by expert interviewees, personal relationships can be used to encourage voluntary compliance with angling regulations but can also encourage decisions based on personal politics over evidence. Weak, or unrealized, linkages were found to occur between the management and resource subsystems, in that the management organization with the most power does not actively participate in developing rules or regulations for C&R beyond limiting the area in which it can occur. Links between the angler and management subsystems are similarly weak, as anglers describe being uninvolved in management decisions or processes (Chapter 7).

An additional finding that contributed to the SES context of the mahseer C&R fishery was the identification of crucial information barriers. Angler reliance on fellow anglers for fishing information shows that information such as research findings must follow an active route whereby the information is shared with key individuals in the angling community and disseminated thusly. Information barriers were also identified between the management organizations such that there is a reliance on individuals who are actively involved with all three organizations (KFD, CWS, WASI) to carry information between them.

This study identifies some of the key linkages between components of the mahseer recreational fishery social-ecological system. Arlinghaus et al. (2017) suggest that researching and managing recreational fisheries from an SES perspective can serve to enhance sustainability by predicting and managing feedback processes and preventing shifts to unwanted states. I conclude that mahseer C&R processes in the recreational fishery SES are unlikely to result in outcome scenarios wherein C&R effects are enhanced in the broader fishery and aquatic SES (Figure 8.1); however, the lack of state oversight and the ongoing introductions of non-native species to the Cauvery River system through the recreational fishery SES render this scenario an ongoing possibility. Work now needs to be done to understand how these components interact in different circumstances, and what feedbacks occur during those interactions to improve predictive capability and foster resilience (Arlinghaus et al. 2013; Arlinghaus et al. 2017), thereby improving the likelihood of positive outcomes.

The Integrated Rapid Assessment Approach

As a process, the integrated rapid assessment protocol provided important insight into the tools available for addressing data deficiencies in developing world recreational fisheries. As discussed in the introduction (Chapter 1), fisheries assessment is broader than population assessment and can be used to address many questions. I applied the rapid assessment technique to determine whether this process would be valuable for addressing data deficiencies by generating information on key variables in C&R fisheries in the developing world, and whether the information gathered would provide support for sustainable management of these fisheries. The rapid assessment process was highly valuable for measuring key variables and identifying important SES linkages, and could be applied in a wide variety of settings and research goals. Outcomes of this assessment were essential for providing both future directions for recreational fisheries research and for providing advice to support sustainable management. Because of the utility and accessibility of this process (it can be duplicated with very little funding and few experts), it is important to discuss some potentially serious caveats to researchers wishing to duplicate or expand on this protocol.

First and foremost, given the rapid nature of each study, there was an ongoing focus on the quantity and quality of the data gathered. It has been said that “no data are better than bad data” (e.g., in reference to online surveys, Duda and Nobile 2010), and maintaining this balance to err on the side of small amounts of good data was a continual challenge. In the rapid assessment process, there is a triangle of trade-offs between funding, time, and data such that it is possible to increase the amount of data gathered, but always at the expense of funding and/or time. As implemented here, the rapid assessment process in a small but important C&R fishery yielded crucial data and did create a holistic image of the fishery tested, but as executed, it was difficult to tease out statistically meaningful results due to small sample sizes. While I would describe the results as being highly significant biologically, I acknowledge that the power of the findings in supporting policy or management changes is somewhat challenged by the lack of statistical power. I would recommend rectifying this issue in one of two ways: combining physiological aspects into a single study and building timeline flexibility into the field study. If the effects of adding additional variables can be accounted for in study planning and power analysis (e.g., through increased use of continuous measurements to avoid excess categorical variables) then a combined study can allow for more fish to be sampled in the confines of a single field session. However, I would caution that if this approach is used practitioners should ensure that the field season chosen reflects pertinent extremes in the fishery, such as periods of highest water temperature, lowest flows, or migration periods. The second suggestion of building flexibility into timelines, beyond the obvious benefit of increased sampling opportunities, will allow researchers to adapt their study plans to conditions more effectively. It can be expected, if the rapid assessment is being carried out on an un-studied fishery, that there will be many unforeseen circumstances that must be accounted for and will result in changing study parameters. For example, the presence of elephant traffic in the Coorg study reach began in the evenings and occurred sporadically throughout the night, severely affecting my ability to gather data at dusk and conduct diel movement studies (Chapter 5). Had I not built in flexible (extended) timelines into my study plan (a lesson learned from the low sample size in Chapter 4) that allowed me to adjust my data-gathering approach, the diel movement portion of my study would have been unusable.

A second consideration for duplicating the rapid assessment process is the involvement of local anglers and experts at all stages. Adopting participatory approaches as much as possible was a goal for this process and was beneficial in a number of ways. Recall that the rapid assessment protocol used in this research endeavours to gather data quickly and cheaply so as to meet the needs of recreational fisheries professionals who are constrained by time and funding limitations. Local anglers and experts are an integral part of bridging the expertise gap that would be faced by a practitioner attempting to carry out a similar study with little personnel support (e.g., see Granek et al. 2008; Cooke et al. 2013 for discussions of angler contributions to research). Indeed, local anglers and experts will be able to provide essential information that will greatly assist in both data-gathering and interpretation (e.g., as seen in assessments of data-poor coastal species, Beaudreau and Levin 2014). While qualified personnel are required to ensure high quality in study design and data consistency, most of the measurements used in this research can be taught to and executed by volunteers. For example, total length, ventilation rate, and reflex impairment indicators can easily be measured by volunteers, provided they are properly trained and supervised.

The third important caveat for duplication of a rapid assessment process involves occasions wherein a naïve (non-resident) researcher performs or supervises the rapid assessment process in another country. It is essential that researchers from other cultures consider their underlying assumptions and cultural differences prior to attempting to analyze and provide recommendations based on their findings (Berkes 2004, 2008, 2009). The importance of this issue was alluded to in Chapter 2, in terms of avoiding prioritizing Western-centric views in global recreational fisheries, but it is equally important in terms of avoiding pitfalls in misunderstanding of findings leading to flawed interpretations that lack cultural context (Berkes 2009). As such, I strongly recommend that researchers or practitioners engaging in a similar rapid assessment process in a country or culture of which they are not a part identify suitable methods for identifying and accounting for their own cultural biases during analysis, and ensure that they are sufficiently immersed in the culture supporting the fishery such that they can pinpoint and account for these differences when designing recommendations. I would also recommend that prior to launching the study of angler behaviours, community views, or economic contributions, that the research team examines the cultural context of the host fishery community to ensure their choice of methodology is appropriate. This could be done by examining typical surveys and interview outputs, for example, in the scientific literature of the host country to gain a deeper sense of how respondents are likely to experience the survey.

Recommendations for Global Recreational Fisheries Research

The results of this work contribute to a small, but important body of research pertaining to developing world recreational fisheries by offering a novel approach that can be used to address widespread deficiencies in the sector. The incorporation of an integrated human dimensions component to the work demonstrated support for the utility of a SES approach in providing context-based interpretation. However, integrated rapid assessments are a first step in data-gathering, and on their own can not address the entirety of research needed. What will be crucial in optimizing the ability of recreational fisheries to act as a positive driver for livelihoods and conservation is increased awareness of the importance of the recreational fishing sector (Cooke and Cowx 2004), and increased monitoring and reporting of recreational fishery statistics (Brownscombe et al. 2014). Failure to respond to this need will likely result in realization of the risks associated with recreational fisheries development, including anthropogenic selection impacts on fish populations (Arlinghaus et al. 2009), introduction of invasive species (Cambray 2003) and potentially even recreational fishing contributions to overfishing (Post et al. 2002; Post 2013).

Future Directions

The results of this work offer a roadmap for future research that can further support sustainable growth and management of the Cauvery River mahseer C&R fishery, and recreational fisheries throughout India. Indeed, the results of Chapter 3 workshop consultations offer a thorough list of future directions. Findings of the biological assessment chapters indicate that further research should be done to clarify the relationship between mahseer body size and increased C&R impacts, such as depressed post-release movement. Given the logistical challenges of ensuring suitable sample sizes of trophy-sized fish, I recommend this aspect be paired with a larger telemetry study that also seeks to clarify potential relationships between body size and migration behaviour and reproductive behaviour.

As recommended by results of Chapter 7, I suggest research examining benefit-sharing relationships between the angling and local communities across India be given priority (also prioritized by participants in Chapter 3 workshops). Improved relationships between these groups established through forms of benefit-sharing would serve to enhance communication and support development of mutually-beneficial conservation plans. Additionally, I recommend further explorations examining angler behaviour throughout the country, including across different recreational fisheries, to generate understanding of plasticity in key behaviours, and to qualitatively explore the relationship between perceived and actual behaviours among anglers. Finally, I recommend a comprehensive, nation-wide economic assessment of the expenditures accrued through recreational fishing activity. I attempted to gather economic data throughout the course of this research, however the swift growth of the industry at the national level and the rapid pace of change within the Cauvery River recreational fishery itself limited the utility of a single-fishery economic assessment. All of this recommended research could be used to better inform and interpret a SES approach to understanding and managing recreational fisheries.

I have further suggestions for future research that are applicable sector-wide, but of particular value to recreational fisheries in the developing world. As noted in several chapters, tools available for use in the field to measure blood parameters (e.g., blood lactate, glucose) have been validated for field use in recreational fisheries research (see Stoot et al. 2014; Sopinka et al. 2016). Their portable nature and quick processing times make these tools extremely valuable for research efforts of this type. Similarly, the non-invasive nature and simplicity of use make whole body stress measurements (such as reflex impairment indicators, ventilation rate) equally appealing as complementary tools, however these measurements require ground-truthing and validation processes also (as noted by Davis 2010). I recommend research that establishes protocols for validating and using these whole-body measurements in extreme field conditions, where they are likely to be needed and few alternatives are available. Net pens are also valuable for remote field studies as they can easily be transported in pieces and assembled on site. The complexity of responses in fishes to holding processes (e.g., Donaldson et al. 2011; Taylor et al. 2011) also suggests a need for protocols guiding validation and ground-truthing the holding process in field studies. Ideally, these recommended protocols would consider the value of these tools in areas where access to complex machinery and logistic support is extremely limited, thereby increasing support for quality data-gathering in challenging conditions.

Conclusion

The flexibility inherent in the rapid assessment approach makes it a suitable first step for addressing data deficiencies in developing world recreational fisheries. The integrated component of the rapid assessment protocol is especially well-suited to researching developing world recreational fisheries as it offers an opportunity to account for local-scale and cultural context when interpreting findings. Thus, an integrated rapid assessment of recreational fisheries can provide important foundational data and can act as a road map towards sustainable management of recreational fisheries, but should not represent the entirety of research conducted on any given fishery or species. In the mahseer C&R recreational fishery of the Cauvery River, the overall impact of angling activity on a biological level was shown to be minor overall, and the rapid assessment process offered sufficiently nuanced results to guide management advice and future research options. Findings of the human dimensions portion of the rapid assessment offered critical context and when examined from a SES perspective, identified important linkages among recreational fishery actors. Future research should examine the influences and feedbacks associated with these linkages, such that drivers can be predicted and accounted for in management actions.

Supplementary Information

Supplementary Information *i*. Chapter 2. Recreational Fisheries Survey
Preliminary Information

1- Please enter the name of your country, or the name of the country in which you are/were employed in the fisheries sector:
2- Please select the level of management which best describes your experience in fisheries:
3- Please select the choice that best describes your area of expertise in fisheries:
4- Please select the choice that best describes your years of experience in fisheries:

Survey Questions

1- Please indicate the degree of **social** and **economic importance** and degree of **ecological/biological impact** of the **commercial**, **subsistence** and **recreational fishing** sectors in your country using the scale from 1 (very unimportant) to 5 (very important) provided in the drop-down menu.

2- Based on the number of participants, amount of **catch** (total **catch**, including fish **voluntarily released**) and economic expenditure, please estimate the size of the **recreational fisheries** in your country. (This included estimates of 'number of participants per year', 'amount of catch per year in tonnes', 'economic expenditures gained per year' and estimates of certainty /references for categories 'total recreational fisheries', 'offshore marine recreational fisheries', 'coastal marine recreational fisheries', and 'freshwater recreational fisheries'.

Please also indicate the relative degree of certainty for any estimates provided using the accompanying drop-down menu. If you are unable to offer an estimate due to a lack of information, please select ‘I don’t know’. (Click on menu to see options.) If you are able to offer estimates and have a reference available, please complete the resource section.

3- Please identify the most important fishery sector (**commercial, subsistence** or **recreational**) in each of your country’s fishing zones and if **recreational fisheries** are not the most important sector, please indicate whether the **commercial** or **subsistence** sectors occupy the same bodies of water (spatial overlap) or target the same species (resource overlap) as those used by **recreational fishers**. If **recreational fisheries** are the most important sector, please leave the overlap fields blank. (This question applied to offshore marine, coastal and freshwater fisheries.)

4- Please estimate the growth potential for recreational fishing in your country over the next decade in terms of harvest and number of participants by completing the sentences below. (A scale of 1-5 from ‘increase considerably’ to ‘decrease considerably’, plus 6- I don’t know’.)

I believe that there is potential for the amount of harvest in the recreational fishing sector in my country to:

I believe that there is potential for the number of participants in the recreational fishery sector of my country to:

5- Which of the following options (on a scale from entirely tourism-based to entirely resident-based) best characterizes the recreational fisheries in your country? (A 6 pt. scale ranging from ‘entirely tourism-based to ‘entirely resident-based’, plus 6- I don’t know.)

Offshore marine recreational fishing in my country is :

Coastal marine recreational fishing in my country is:

Freshwater recreational fishing in my country is :

6- Are competitive fishing events permitted in your country?

Yes/No

If you answered 'Yes' above, please use the drop-down menu provided to describe the frequency of competitive fishing events that occur in the offshore marine, coastal marine and freshwater recreational fisheries in your country. (Options ranged from 'frequently' to 'never' on a four pt scale ('always' was omitted), plus 5- I don't know.) If your country hosts any national or international tournaments, please describe them briefly in the space provided (Open ended).

7- On a scale from 'Entirely harvest-oriented' to 'Entirely voluntary catch-and-release' , please indicate which option best describes the overall recreational fishing practices in your country and describe the fishing practices for the three most commonly targeted species in your country's recreational fishing sector.

Overall, the recreational fishing practices in my country are: (Options ranged from 'entirely catch and release oriented' to 'entirely harvest oriented' on a 5 pt. scale, plus 6- I don't know).

Open-ended options for listed the top 3 target species included pull-down menus for target locations (offshore, coastal, freshwater) and the same 6 pt. scale per fishery.

8- In order of importance from 1 to 3, please list the top three most important **management needs** and **policy needs** you feel should be prioritized in managing your country's **recreational fisheries**. (Open-ended.)

9- In order of importance from 1 to 3, please list the top three most important **knowledge gaps** and **development gaps** that pertain to your country's **recreational fisheries**. (Open-ended.)

10- Do your country's fisheries management plans include specific strategies (i.e. catch/size limits, gear types, seasonal closures, etc.) for managing recreational fisheries in freshwater, coastal and/or offshore areas?

Yes/No

If you answered 'yes', please describe them briefly and include the type of management body responsible and the body of ownership, if different from that of the management body. Drop-down menus were provided for categories labelled 'offshore recreational fisheries', 'coastal recreational fisheries' and 'freshwater recreational fisheries'. Each contained a menu of 9 possible management and ownership bodies. Management unit/ Ownership body options: national agency, state agency, regional fisher community association, local fisher community association, regional fisher clubs, local fisher clubs, private governance or ownership, Non-Governmental Organization (NGO), I don't know. Management strategies for each of the three categories were open-ended.

11- Are there any specific issues in your country that would constrain the sustainable growth of your country's recreational fisheries?

Yes/No

If you answered 'yes', please describe them briefly. (Open-ended.)

12- Please briefly describe any areas of potential **social, biological or economic conflict** surrounding the development of **recreational fisheries** in your country. (Open-ended.)

13- Are there any comments you would like to add regarding any emerging issues that you feel would influence the **governance**, **management** or growth of **recreational fisheries** in your country? (Open-ended.)

Chapter 2: Operational Definitions (in Alphabetical Order)

Catch: Defined here as the total number of live animals caught during fishing activities, not solely those retained for distribution or consumption.

Commercial fisheries: Those fisheries (whether large scale, small-scale and/or artisanal) undertaken for the purpose of sale on the commercial market or through other forms of trade (FAO, 2005).

Commonly targeted species: Defined here as a very commonly fished or iconic species that is targeted during recreational fishing.

Competitive fishing event: Defined here as a competitive event targeting a specific species or group of species in which fishers compete and winners are judged based on criteria such as catch size, weight, etc.

Constraint: Defined here as any variable related to recreational fishing that is known or suspected to present difficulties or unwanted complexity in sustainable management of the aquatic ecosystem.

Coastal marine fisheries: Defined here as salt water fishing activities which occur in coastal zones.

Development gaps: Defined here as the areas of organizational, infrastructure or social development that are considered essential to successful, sustainable resource management but are either lacking or unavailable.

Ecological/biological impact (of recreational fishing): Defined here as the degree to which fisheries contribute to negative impacts on the ecological and/or biological components of the ecosystem.

Economic importance: Defined here as any and all economic factors (including, but not limited to employment, labour costs, interest rates, inflation, etc.) that may benefit from or be constrained by commercial, subsistence or recreational fisheries sectors.

Fisher: Any person of any age, gender, culture or socio-economic status who participates in fishing activities of any type (FAO, 1998).

Fisheries management: The integrated process of information gathering, analysis, planning, decision making, allocation of resources and formulation and enforcement of fishery regulations by which the fisheries management authority controls the present and future behaviours of the interested parties in the fishery, in order to ensure the continued productivity of the living resources (FAO, 1995).

Governance: Defined here as the sum of legal, social, economic and political factors involved in governing at multiple scales (i.e. local, national, international). This also includes the process of governing, the individuals involved in, and the manner/ methodology employed in the process of governing.

Harvest-oriented fisheries: Defined here as those fisheries which target fish for consumption and/or resource-related harvest but do not commonly return unwanted fish to the water.

Freshwater fisheries: Defined here as those fisheries which occur apart from the ocean, typically in fresh water bodies such as lakes, rivers and streams but may include inland brackish water bodies and confluences (FAO, 2005).

Knowledge gaps: The areas of knowledge/research that are considered essential to successful, sustainable resource management but are either lacking or unavailable.

Management needs: Defined here as any and all institutional, structural, regulatory, legislative, informational or applied tools required to manage recreational fisheries effectively and in a sustainable manner.

Marine fisheries: Defined here as those fisheries which target species in salt or brackish waters such as oceans, estuaries and lagoons (FAO, 2005).

Offshore marine fisheries: Defined here as salt water fisheries activities which occur beyond coastal zones but within a country's Exclusive Economic Zone (EEZ) boundaries.

Policy needs: Defined here as any and all tools required to establish goals, objectives and strategies to guide management of recreational fisheries effectively and in a sustainable manner.

Recreational fishing: Any type of fishing (including, but not limited to angling, netting and spear fishing) that does not constitute the fishers' primary source of food, nor is it used to sell or trade on the commercial market (FAO, 2012).

Resident-based (recreational fishing): Defined here as recreational fishing activities undertaken by individuals who live in the host country, state or locality on a permanent basis.

Social importance: Defined here as any and all social factors (including, but not limited to religion, ethnicity, family, education, cultural attributes, etc.) that may derive benefit from or be constrained by activities related to the commercial, subsistence or recreational fisheries sectors.

Subsistence fisheries: Fisheries in which harvested fish are consumed directly by the fisher/kin and not sold or traded (FAO, 1998).

Sustainable growth: Defined here as the expansion of recreational fisheries activities, as measured by increased participation, increased catch or harvest and/or an increase in economic benefits, that does not significantly reduce virgin target population sizes nor negatively impacts ecological or cultural systems in a manner that prevents rehabilitation or mitigation.

Tourism-based (recreational fishing): Defined here as recreational fishing activities undertaken by individuals who do not live in the host country, state or locality on a permanent basis (i.e. non-resident to the fished area).

Voluntary catch-and-release: Defined here as the unlegislated practice of returning all or most fish to the water after catch on the basis of conservation, desirability and/or palatability.

Chapter 2: Sources

FAO. 1995. Guidelines for responsible management of fisheries. In, Report of the Expert Consultation on Guidelines for Responsible Fisheries Management. Wellington, New Zealand. FAO Fisheries Report No. 519.

FAO. 1998. Guidelines for the routine collection of capture fishery data. FAO Fish. Tech. Pap, 382: 113p.

FAO. 2005. Fisheries and Aquaculture topics. Types of Fisheries, Topics Fact Sheets. In: FAO Fisheries and Aquaculture Department. Rome. http://www.fao.org/fishery/topic/12306/en

FAO. 2012. Recreational Fisheries. Technical Guidelines for Responsible Fisheries. No. 13. Rome, FAO. 176p.

Supplementary Information *ii*. Chapter 7. Cauvery River Mahseer Angler Survey

Part 1- Background

These questions are designed to identify common attributes of mahseer recreational anglers who fish on the Cauvery River.

1. How long have you been a recreational fisher? Please select one of the following:

☐ Less than 1 year ☐ 1-5 years ☐ 5-10 years ☐ 10-15 years ☐ More than 15 years

2. How would you rate your recreational fishing expertise? Please select one of the following:

☐ Beginner ☐ Intermediate ☐ Expert ☐ Prefer not to say

3. How did you learn to fish? Please select all that apply.

☐ I'm self-taught

☐ I learned from a family member

☐ I learned from a friend

☐ I learned from a professional instructor

☐ None of these responses apply to me

Part 2- Angling Methods and Behaviours

These questions are designed to identify common methods of fishing used by mahseer anglers on the Cauvery River.

4. How often do you seek out information about recreational fishing techniques? Please choose the option that best describes your approach to learning about fishing.

- ☐ I never seek out information about recreational fishing
- ☐ I rarely seek out information about recreational fishing
- ☐ I sometimes seek out information about recreational fishing
- ☐ I frequently seek out information about recreational fishing

5. What sources do you use to seek out information on fishing? Please check all that apply, and describe how much you value these sources by assigning a rating to each source ranging from 1- very important to 5- very unimportant.

☐ I get fishing information from family/friends	☐ Importance
☐ I get fishing information from magazines	☐ Importance
☐ I get fishing information from internet sources	☐ Importance
☐ I get fishing information from books	☐ Importance
☐ I get fishing information from people I fish with	☐ Importance
☐ I get fishing information from TV shows	☐ Importance
☐ I don't seek out information on fishing	

6. For each information source that you listed in the previous question, please rate the source according to how trustworthy you feel the information is (on a scale ranging from 1- trust completely to 5- don't trust at all).

Source	Trust rating (1- 5)
Family/friends	☐
Magazines	☐
Internet sources	☐
Books	☐
People I fish with	☐
TV shows	☐

7. Which of the following statements describe circumstances in which you are more likely to **permanently** alter your angling behaviour based on advice from an outside source (such as those listed in Question 6)? Please choose all that apply. If you choose 'Other', please describe a different situation where you might change your fishing practices.

☐ I change my fishing practices when I agree with the advice that I'm given

☐ I change my fishing practices when I've tried out the advice and it proves to be sound

☐ I change my fishing practices when a source I trust suggests it

☐ I change my fishing practices when the fish I catch don't recover well

☐ I change my fishing practices when I receive advice from an expert angler

☐ I have never changed my fishing practices

☐

Other:____

8. Which one of the following options best describes your species preferences when fishing?

☐ I fish only for mahseer

☐ I prefer to fish for mahseer, but will sometimes fish for other species

☐ I prefer to fish for other species, but will sometimes fish for mahseer

☐ I prefer to fish for other species and won't fish for mahseer

☐ I will fish for any fish I can catch

☐ None of these statements apply to me

Answer question 9 only if you fish for multiple species. If you ONLY fish for one species, please skip to question 10.

9. The different methods used for angling can include what type of gear you use to catch fish, how long fish are played on the line, and whether fish are kept or released. How similar are your angling methods when you target mahseer to when you target other species?

☐ I fish the same way for all fish that I catch

☐ I fish slightly differently for mahseer than I do for other fish species

☐ I fish very differently for mahseer than I do for other fish species

☐ I fish differently for all of the different types of fish that I catch

10. Which of the following options best describes what you do with the mahseer that you catch?

- ☐ I release all of the mahseer that I catch
- ☐ I release most of the mahseer that I catch
- ☐ I keep and release mahseer in equal numbers
- ☐ I keep most of the mahseer that I catch
- ☐ I keep all of the mahseer that I catch
- ☐ None of these statements apply to me

11. Which of the following lure types do you use when fishing for mahseer? Please check all that apply, and describe how often you use them by assigning a rating ranging from 1- very rarely to 5- very frequently.

☐ Ragi on barbed single hooks	☐ Frequency (1-5)
☐ Ragi on barbless single hooks	☐ Frequency (1-5)
☐ Live bait on barbed treble hooks	☐ Frequency (1-5)
☐ Live bait on barbless treble hooks	☐ Frequency (1-5)
☐ Lures with barbed treble hooks	☐ Frequency (1-5)
☐ Lures with barbless treble hooks	☐ Frequency (1-5)
☐ Lures with barbed single hooks	☐ Frequency (1-5)
☐ Lures with barbless single hooks	☐ Frequency (1-5)

12. Which of the following attributes are important to you when fishing for mahseer? Please rank the attributes in importance ranging from 1- very important to 5- least important. If the listed attribute isn't important to you at all, please assign a 6 (not important at all) for that attribute.

How important is it that you…

catch mahseer that put up a strong fight ☐ Importance (1-5, or 6)

catch mahseer that put up a long fight ☐ Importance (1-5, or 6)

catch mahseer that look strong and healthy when I catch them ☐ Importance (1-5, or 6)

catch mahseer that look strong and healthy when I release them ☐ Importance (1-5, or 6)

catch big mahseer ☐ Importance (1-5, or 6)

catch mahseer using good fishing technique ☐ Importance (1-5, or 6)

catch at least one fish (of any species) ☐ Importance (1-5, or 6)

13. How frequently do you take photos of mahseer that you catch before you release them?

☐ I take photos of all of the mahseer that I catch

☐ I take photos of most of the mahseer that I catch

☐ I take photos of some of the mahseer that I catch

☐ I rarely take photos of the mahseer that I catch

☐ I never take photos of mahseer that I catch

14. Which of the following statements best describe why you take photos of mahseer? Please check all that apply. If you choose 'Other', please describe why you choose to take photos of mahseer.

- ☐ I take photos when I catch big mahseer
- ☐ I take photos when I catch mahseer that look robust/healthy
- ☐ I take photos when I catch mahseer that put up a good fight
- ☐ I take photos when I catch mahseer to remind me of the experience
- ☐ I take photos when I catch mahseer so I can show other people
- ☐ None of these statements apply to me
- ☐ Other: ____

15. Which of the following statements describe how you take photos of mahseer? Please check all that apply, whether the actions are performed by you, by a ghillie, or by another associate. If you choose 'Other', please describe how you take photos of mahseer.

- ☐ I keep the mahseer in the water when I take photos
- ☐ I lift the mahseer out of the water when I take photos, holding them by the tail and supporting the body
- ☐ I lift the mahseer out of the water when I take photos, holding them by the gills
- ☐ I lift the mahseer out of the water when I take photos, holding them by a stringer
- ☐ I weigh the mahseer I catch, prior to or after taking photos

☐ None of these statements apply to me

☐ Other: ____

Part 3- Angler Perspectives

These final questions are designed to identify angler perspectives on the mahseer recreational fishery of the Cauvery River.

16. How would you describe the current status of mahseer populations in the Cauvery River? Please select the response that best applies:

    Mahseer populations in the Cauvery River are:

    ☐ Extremely threatened

    ☐ Somewhat threatened

    ☐ Neither threatened nor secure

    ☐ Somewhat secure

    ☐ Extremely secure

    Or: ☐ None of these statements apply to the mahseer populations of the Cauvery River

17. How would you describe your views on Cauvery River conservation projects? Please select the response that best applies:

    ☐ I strongly oppose Cauvery River conservation projects

    ☐ I somewhat oppose Cauvery River conservation projects

    ☐ I neither oppose nor support Cauvery River conservation projects

- ☐ I somewhat support Cauvery River conservation projects
- ☐ I strongly support Cauvery River conservation projects
- ☐ None of these statements apply to me

18. How would you describe your views on Cauvery River mahseer conservation projects? Please select the response that best applies:

- ☐ I strongly oppose mahseer conservation projects on the Cauvery River
- ☐ I somewhat oppose mahseer conservation projects on the Cauvery River
- ☐ I neither oppose nor support mahseer conservation projects on the Cauvery River
- ☐ I somewhat support mahseer conservation projects on the Cauvery River
- ☐ I strongly support mahseer conservation projects on the Cauvery River
- ☐ None of these statements apply to me

19. How do fishing rules and regulations impact the way you fish for mahseer? Please choose the answer that best describes your opinion.

- ☐ Fishing regulations have no impact on my fishing practices
- ☐ Fishing regulations have some impact on my fishing practices
- ☐ Fishing regulations have a lot impact on my fishing practices

20. How would you describe the level of value placed on your input for local mahseer recreational fisheries management decisions? Please choose the answer that best describes your opinion.

- ☐ My input is always dismissed in local recreational fisheries management decisions
- ☐ My input is sometimes dismissed in local recreational fisheries management decisions
- ☐ My input is neither valued nor dismissed in local recreational fisheries management decisions
- ☐ My input is sometimes valued in local recreational fisheries management decisions
- ☐ My input is always valued in local recreational fisheries management decisions
- ☐ I have no input to contribute to local recreational fisheries management decisions

21. How would you describe the current quality of local recreational fisheries management decisions? Please choose the answer that best describes your opinion.

Local mahseer recreational fisheries management decisions are of:

- ☐ Very high quality
- ☐ High quality
- ☐ Neither high quality nor low quality
- ☐ Low quality
- ☐ Very low quality

☐ I don't know

22. Do you think current fishing regulations for the mahseer recreational fishery on the Cauvery River are reasonable? Please choose the answer that best describes your opinion.

☐ Yes ☐ No ☐ Neither reasonable nor unreasonable ☐ I don't know

23. If you answered no to the above, please choose the changes you think would better suit the mahseer fishery. Please check all that apply.

☐ I think I should be allowed to keep more mahseer

☐ I think I should be allowed to keep all mahseer

☐ I don't think I should be allowed to keep any mahseer

☐ I think I should be allowed to keep small mahseer only

☐ I think I should be allowed to keep large mahseer only

☐ I think I should be allowed to keep medium sized mahseer only

☐ I don't think fishing for mahseer should be allowed

☐ I think mahseer fishing should be restricted to certain types of gear and lures

☐ I think mahseer fishing should be restricted to fewer locations

☐ I think mahseer fishing should be allowed in more locations

☐ I think mahseer fishing seasons should be shorter

☐ Other (Please describe):

____

Part 4: Optional Demographic Questions

24. What is your age? Please select one of the following:

☐ Under 15 ☐ 15-25 ☐ 25-35 ☐ 35-45 ☐ 45-60 ☐ 60+ ☐ Prefer not to say

25. What is your gender? Please select one of the following:

☐ Male ☐ Female ☐ Prefer not to say

END. This marks the end of the mahseer angler survey. On behalf of our team, thank you very much for your participation!

Supplementary Information *iii*. Chapter 7. Local Expert Interview Questions

1. Could you please describe your organization and position, as it relates to the mahseer C&R fishery?
2. How many years have you been with this organization?
3. How many years have you been in this position within the organization?
4. Do you like the position you hold in the organization?
5. What sort of work or volunteer work did you do prior to joining the organization?

Break to clarify the definition of management, which will be delivered in lay terms based on the following formal definition: "The integrated process of information gathering, analysis, planning, consultation, decision-making, allocation of resources and formulation and implementation, with enforcement as necessary, of regulations or rules which govern fisheries activities in order to ensure the continued productivity of the resources and the accomplishment of other fisheries objectives (Cochrane 2002)."

This definition will be described as "Fisheries management refers to any work or volunteer efforts that help to conduct research, planning, decision-making, resourcing, or enforcing rules or guidelines for fisheries-related activities, including commercial, subsistence, recreational activities that directly or indirectly impact fish populations."

Content Questions:

6. What organization(s) do you view as being responsible for managing the mahseer C&R fishery?
7. How would you describe your organization's role in managing the mahseer C&R fishery?

8. Is your organization responsible for implementing and enforcing regulations in the mahseer C&R fishery? If yes, which ones?
9. Are there any policies your organization promotes, but doesn't necessarily enforce, in the mahseer C&R fishery? (Prompt: Policies can refer to ideals, behaviours, plans, or formal policies.)
10. Are there any other organizations you feel play a valuable role in managing the mahseer C&R fishery? (Prompt: Refer back to answer for question 1, and ask if there are any other people or organizations that are also occasionally involved in managing mahseer C&R, and in what circumstances.)
11. How would you describe the way the organizations managing the mahseer C&R fishery relate to one another? Are you comfortable providing an example of the way these organizations relate to one another? (Prompt: Would you describe the relationships among these organizations as cooperative, neutral, or antagonistic?)
12. Are there any individuals or organizations you feel are having a particularly positive impact on the fishery or fish populations? Are you comfortable giving an example of a time you noticed a person or organization having a positive impact? (Prompt: When you think about the management process and what is involved in managing the fishery, are there any people or organizations that play a particularly positive role?)
13. Are there any individuals or organizations you feel are having a particularly negative impact on the fishery or fish populations? Are you comfortable giving an example of a time you noticed a person or organization having a negative impact? (Prompt: When you think about the management process and what is involved in managing the fishery, are there any people or organizations that play a particularly negative role?)

14. How would you describe the degree to which personal relationships play a role in decision-making in the mahseer C&R fishery? Are you comfortable providing an example of a time when personal relationships played or didn't play a role in a decision involving the mahseer C&R fishery? (Prompt: Do you feel that familial, friendly, or business relationships are an important part of the decision-making process in managing the mahseer C&R fishery?)
15. Do you think local community members like the mahseer C&R fishery? Do you think they gain any benefits from having the fishery in the community?
16. How do you think anglers would describe the relationships among the organizations managing the mahseer C&R fishery?
17. Do you think anglers would describe the regulations (described in question 8) your organization uses to manage the mahseer C&R fishery as positive, negative, or neutral? Are you comfortable with giving an example of a time you noticed an angler or anglers responding to a regulation?
18. Do you think anglers follow the rules for mahseer C&R fishing? Are there any particular rules or guidelines you think are followed more or less than others? Why do you think this (these) rules or guidelines are followed more (or less) than others?
19. Is there anything you feel should be done differently in managing the mahseer C&R fishery?
20. Is there anything you wish anglers would do differently when fishing for mahseer?
21. What do you think the future holds for the mahseer C&R fishery?
22. Are there any important topics you feel should be addressed by researchers who study the mahseer C&R fishery?

23. How valuable do you think research into the mahseer C&R fishery is?
24. Are you familiar with the findings of any studies that have been conducted on the mahseer C&R fishery or on mahseer more generally? If yes, which studies are you familiar with?
25. (If yes) Do you feel those findings have been of value to your organization?
26. Is there anything you think researchers or other organizations can do to make research findings more valuable to your organization?
27. Have these questions brought any topics to mind regarding the management of the mahseer C&R fishery that you think are important to consider?

Thanks, and conclude: Can you recommend any other individuals we should speak to?

References

Aas, Ø., Haider, W., and Hunt, L. (2000). Angler responses to potential harvest regulations in a Norwegian sport fishery: a conjoint-based choice modeling approach. *North American Journal of Fisheries Management*, *20*(4), 940-950.

Aas, Ø. (2002). Multicultural and cross-disciplinary progress in evaluating recreational fisheries. In T. Pitcher and C.E. Hollingworth (Eds.), *Recreational fisheries: ecological, economic and social evaluation*. Blackwell Publishing Ltd, Oxford, UK. 252 – 263 pp.

Abbot, J., and Guijt, I. (1997). Changing views on change: A working paper on participatory monitoring of the environment. International Institute for Environment and Development (IIED), London, UK. 96p.

Allen, W., Fenemor, A., Kilvington, M., Harmsworth, G., Young, R. G., Deans, N., Horn, C., Phillips, C., Montes de Oca, O., Ataria, J., and Smith, R. (2011). Building collaboration and learning in integrated catchment management: the importance of social process and multiple engagement approaches. *New Zealand Journal of Marine and Freshwater Research*, *45*(3), 525-539.

Allison, E. H., Perry, A. L., Badjeck, M. C., Adger, N.W., Brown, K., Conway, D., Halls, A.S., Pilling, G.M., Reynolds, J.D., Andrew, N.L. and Dulvy, N. K. (2009). Vulnerability of national economies to the impacts of climate change on fisheries. *Fish and Fisheries*, 10(2), 173-196.

Anderies, J., Janssen, M., and Ostrom, E. (2004). A framework to analyze the robustness of social-ecological systems from an institutional perspective. *Ecology and society*, *9*(1).

Anderson, J. L., Anderson, C. M., Chu, J., Meredith, J., Asche, F., Sylvia, G., Smith, M.D>, Anggraeni, D., Arthur, R., Guttormsen, A., McCluney, J. K., Ward, T., Akpalu, W., Eggert, H., Flores, J., Freeman, M., Holland, D.S., Knapp, G., Kobayashi, M., Larkin, S., MacLauchlin, K., Schnier, K., Soboil, M., Tveteras, S., Uchida, H., and Valderrama, D. (2015). The fishery performance indicators: a management tool for triple bottom line outcomes. *PLoS One*, *10*(5), e0122809.

Andrew, N. L., Béné, C., Hall, S. J., Allison, E. H., Heck, S., and Ratner, B. D. (2007). Diagnosis and management of small-scale fisheries in developing countries. *Fish and Fisheries*, 8(3), 227-240.

Arlinghaus, R., Mehner, T., and Cowx, I.G. (2002). Reconciling traditional inland fisheries management and sustainability in industrialized countries, with emphasis on Europe. *Fish and Fisheries*, 3(4), 261-316.

Arlinghaus, R. (2004). A human dimensions approach towards sustainable recreational fisheries management. Turnshare Ltd.-Publisher. London, UK. 158pp.

Arlinghaus, R. (2005). A conceptual framework to identify and understand conflicts in recreational fisheries systems, with implications for sustainable management. *Aquatic Resources, Culture and Development*, 1(2), 145-174.

Arlinghaus, R. (2006). Overcoming human obstacles to conservation of recreational fishery resources, with emphasis on central Europe. *Environmental Conservation*, *33*(01), 46-59.

Arlinghaus, R. (2007). Voluntary catch-and-release can generate conflict within the recreational angling community: a qualitative case study of specialised carp, *Cyprinus carpio*, angling in Germany. *Fisheries Management and Ecology*, *14*(2), 161-171.

Arlinghaus, R., Cooke, S. J., Lyman, J., Policansky, D., Schwab, A., Suski, C., Sutton, S., and Thorstad, E. B. (2007). Understanding the complexity of catch-and-release in recreational fishing: an integrative synthesis of global knowledge from historical, ethical, social, and biological perspectives. *Reviews in Fisheries Science*, *15*(1-2), 75-167.

Arlinghaus, R., Cooke, S. J., Schwab, A., and Cowx, I. G. (2007). Fish welfare: a challenge to the feelings-based approach, with implications for recreational fishing. *Fish and Fisheries*, 8(1), 57-71.

Arlinghaus, R., and Cowx, I. G. (2008). Meaning and Relevance of the Ecosystem Approach to Recreational Fisheries Management: Emphasis on the Importance of the Human Dimension. In: Aas, Ø (Ed.) *Global challenges in recreational fisheries*. Blackwell Publishing, Ltd. New Jersey, USA. 56-74 pp.

Arlinghaus R., Klefoth T., Cooke S.J., Gingerich A. and Suski C. (2009) Physiological and behavioural consequences of catch-and-release angling on northern pike (*Esox lucius* L.). *Fisheries Research*, *97*, 223-233.

Arlinghaus, R., Schwab, A., Riepe, C., and Teel, T. (2012). A primer on anti-angling philosophy and its relevance for recreational fisheries in urbanized societies. *Fisheries*, 37(4), 153-164.

Arlinghaus, R., Cooke, S. J., and Potts, W. (2013). Towards resilient recreational fisheries on a global scale through improved understanding of fish and fisher behaviour. *Fisheries Management and Ecology*, *20*(2-3), 91-98.

Arlinghaus, R., and Krause, J. (2013). Wisdom of the crowd and natural resource management. *Trends in Ecology and Evolution*, *28*(1), 8-11.

Arlinghaus, R., Tillner, R., and Bork, M. (2015). Explaining participation rates in recreational fishing across industrialized countries. *Fisheries Management and Ecology*, 22, 45–55.

Arlinghaus, R., Cooke, S. J., Sutton, S. G., Danylchuk, A. J., Potts, W., de M.F.Freire, K., Alós, J., da Silva, E.T., Cowx, I.G. and van Anrooy, R. (2016). Recommendations for the future of recreational fisheries to prepare the social-ecological system to cope with change. *Fisheries Management and Ecology*, 23(3-4), 177-186.

Arlinghaus, R., Alós, J., Beardmore, B., Daedlow, K., Dorow, M., Fujitani, M., Hühn, D., Haider, W., Hunt, L.M., Johnson, B.M., Johnston, F., Klefoth, T., Matsumura, S., Monk, C., Pagel, T., Post, J.R., Rapp, T., Riepe, C., Ward, H. and Wolter, C. (2017). Understanding and managing freshwater recreational fisheries as complex adaptive social-ecological systems. *Reviews in Fisheries Science and Aquaculture,* 25(1), 1-41.

Arlinghaus, R., Laskowski, K. L., Alós, J., Klefoth, T., Monk, C. T., Nakayama, S., and Schröder, A. (2017). Passive gear-induced timidity syndrome in wild fish populations and its potential ecological and managerial implications. *Fish and Fisheries*, 18(2), 360-373.

Armitage, D. R., Plummer, R., Berkes, F., Arthur, R. I., Charles, A. T., Davidson-Hunt, I. J., Diduck, A. P., Doubleday, N. C., Johnson, D. S., Marschke, M., McConney, P., Pinkerton, E. W., and Wollenberg, E. K. (2008). Adaptive co-management for social-ecological complexity. *Frontiers in Ecology and the Environment*, *7*(2), 95-102.

Alexiades, A. V., Flecker, A. S., and Kraft, C. E. (2017). Non-native fish stocking alters stream ecosystem nutrient dynamics. *Ecological Applications*, *27*(3), 956-965.

Barnett, A., Abrantes, K. G., Baker, R., Diedrich, A. S., Farr, M., Kuilboer, A., Mahony, T., McLeod, I., Moscardo, G., Prideaux, M., Stoeckl, N., van Luyn, A. and Sheaves, M. (2016).

Sportfisheries, conservation and sustainable livelihoods: a multidisciplinary guide to developing best practice. *Fish and Fisheries*, *17*(3), 696-713.

Barreto, R. E., Luchiari, A. C., and Marcondes, A. L. (2003). Ventilatory frequency indicates visual recognition of an allopatric predator in naïve Nile tilapia. *Behavioural Processes*, *60*(3), 235-239.

Barreto, R. E., and Volpato, G. L. (2004). Caution for using ventilatory frequency as an indicator of stress in fish. *Behavioural Processes*, *66*(1), 43-51.

Barreto, R. E., and Volpato, G. L. (2011). Ventilation rates indicate stress-coping styles in Nile tilapia. *Journal of Biosciences*, *36*(5), 851-855.

Bartholomew A. and Bohnsack, J.A. (2005) A review of catch-and-release angling mortality with implications for no-take reserves. *Reviews in Biology and Fisheries, 15*, 129-154.

Bartley, D. M., de Graaf, G. J., Valbo-Jørgensen, J. and Marmulla, G. (2015). Inland capture fisheries: status and data issues. *Fisheries Management and Ecology*, 22(1), 71-77.

Barton, B. A., Schreck, C. B., and Sigismondi, L. A. (1986). Multiple acute disturbances evoke cumulative physiological stress responses in juvenile chinook salmon. *Transactions of the American Fisheries Society*, *115*(2), 245-251.

Barton B. (2002) Stress in Fishes: A diversity of responses with particular reference to changes in circulating corticosteroids. *Integrative and Comparative Biology, 42*(3), 517-525.

Bates, D., Maechler, M., Bolker, B., and Walker, S. (2015). Fitting Linear Mixed-Effects Models Using lme4. *Journal of Statistical Software, 67*(1), 1-48.

Beard, T. D., Arlinghaus, R., Cooke, S. J., McIntyre, P. B., De Silva, S., Bartley, D., and Cowx, I. G. (2011). Ecosystem approach to inland fisheries: research needs and implementation strategies.

Beaudreau, A. H., and Levin, P. S. (2014). Advancing the use of local ecological knowledge for assessing data-poor species in coastal ecosystems. *Ecological Applications*, *24*(2), 244-256.

Berkes, F., and Folke, C. (1998). Linking social and ecological systems for resilience and sustainability. In Berkes, F., Folke, C. (Eds.) *Linking social and ecological systems: management practices and social mechanisms for building resilience*. Cambridge University Press, Cambridge, UK. 25 p.

Berkes, F. (2004). Rethinking community-based conservation. *Conservation biology*, *18*(3), 621-630. 362 p.

Berkes, F. (2008). Sacred ecology, 2nd edition. Routledge, New York, USA.

Berkes, F. (2009). Indigenous ways of knowing and the study of environmental change. *Journal of the Royal Society of New Zealand, 39(4)*, 151-156.

Berkes F., Arce-Ibarra M., Armitage D., Charles A., Loucks L., Makino M., Satria A., Seixas C., Abraham J., and Berdej S. (2016). Analysis of Social-Ecological Systems for Community Conservation. Community Conservation Research Network, Halifax, Canada. 45 p. Available online at: http://www.communityconservation.net/resources/social-ecological-systems.

Bettoli, P. W., and Osborne, R. S. (1998). Hooking mortality and behavior of striped bass following catch and release angling. *North American Journal of Fisheries Management*, *18*(3), 609-615.

Beaudreau, A. H., and Levin, P. S. (2014). Advancing the use of local ecological knowledge for assessing data-poor species in coastal ecosystems. *Ecological Applications*, *24*(2), 244-256.

Bhatt, J. P., Nautiyal, P., and Singh, H. R. (2004). Status (1993-1994) of the endangered fish Himalayan Mahseer *Tor putitora* (Hamilton)(*Cyprinidae*) in the mountain reaches of the river Ganga. *Asian Fisheries Science*, *17*, 341-355.

Bhatt, J. P., and Pandit, M. K. (2016). Endangered Golden mahseer *Tor putitora* Hamilton: a review of natural history. *Reviews in Fish Biology and Fisheries*, *26*(1), 25-38.

Bower S.D., Nguyen V.M., Danylchuk A.J., Beard Jr. T.D., and Cooke S.J. (2014) Inter-sectoral conflict and recreational fisheries of the developing world: Opportunities and challenges for co-operation. In McConney, P., Medeiros, R., and Pena, M. (Eds.) *Enhancing Stewardship in Small-Scale Fisheries: Practices and Perspectives*. Too Big to Ignore (TBTI) and Centre for Resource Management and Environmental Studies, The University of the West Indies, Cave Hill Campus, Barbados. CERMES Technical Report No. 73, 88-97.

Bower, S. D., Danylchuk, A. J., Raghavan, R., Clark-Danylchuk, S. E., Pinder, A. C., and Cooke, S. J. (2016). Rapid assessment of the physiological impacts caused by catch-and-release angling on blue-finned mahseer (*Tor* sp.) of the Cauvery River, India. *Fisheries Management and Ecology*, *23*(3-4), 208-217.

Bower, S. D., Danylchuk, A. J., Brownscombe, J. W., Thiem, J. D., and Cooke, S. J. (2016). Evaluating effects of catch-and-release angling on peacock bass (*Cichla ocellaris*) in a Puerto Rican reservoir: a rapid assessment approach. *Fisheries Research*, *175*, 95-102.

Bower, S. D., Danylchuk, A. J., Raghavan, R., Danylchuk, S. C., Pinder, A. C., Alter, A. M., and Cooke, S. J. (2017). Involving recreational fisheries stakeholders in development of research and conservation priorities for mahseer (*Tor* spp.) of India through collaborative workshops. *Fisheries Research*, *186*, 665-671.

Bower, S.D., Raghavan, R., Danylchuk, A.J., Mahesh, N., and Cooke, S.J. (In Review). Identifying sub-lethal behavioural responses of *Tor khudree* to catch-and-release recreational angling using radio telemetry. Fisheries Research, WRFC8 Special Issue.

Brownscombe, J. W., Thiem, J. D., Hatry, C., Cull, F., Haak, C. R., Danylchuk, A. J., and Cooke, S. J. (2013). Recovery bags reduce post-release impairments in locomotory activity and behavior of bonefish (*Albula* spp.) following exposure to angling-related stressors. *Journal of Experimental Marine Biology and Ecology*, *440*, 207-215.

Bryan, H. M., Darimont, C. T., Paquet, P. C., Wynne-Edwards, K. E., and Smits, J. E. (2013). Stress and reproductive hormones in grizzly bears reflect nutritional benefits and social consequences of a salmon foraging niche. *PloS One*, *8*(11), e80537.

Campbell, M. D., Patino, R., Tolan, J., Strauss, R., and Diamond, S. L. (2009). Sub-lethal effects of catch-and-release fishing: measuring capture stress, fish impairment, and predation risk using a condition index. *ICES Journal of Marine Science*, *67*(3), 513-521.

Cambray, J. A. (2003). Impact on indigenous species biodiversity caused by the globalisation of alien recreational freshwater fisheries. *Aquatic Biodiversity*, 217-230.

Caro, T. (1999). The behaviour–conservation interface. *Trends in Ecology and Evolution, 14*(9), 366-369.

Centre for Environment, Fisheries and Aquaculture Science (CEFAS). (2013). Data Deficient Fisheries in EU Waters. European Parliament Committee on Fisheries, Brussels, Belgium. 74 p.

Central Water Commission. (2012). Hydrological Data Directorate, Information Systems Organization, Water Planning and Projects Wing. Central Water Commission, New Delhi, IN. 680 p.

Chu, C., Mandrak, N. E., and Minns, C. K. (2005). Potential impacts of climate change on the distributions of several common and rare freshwater fishes in Canada. *Diversity and Distributions*, *11*(4), 299-310.

Cisneros-Montemayor, A. M., and Sumaila, U. R. (2010). A global estimate of benefits from ecosystem-based marine recreation: potential impacts and implications for management. *Journal of Bioeconomics*, 12(3), 245-268.

Clark, M. (2017). Repeated Measures and Mixed Models. https://m-clark.github.io/docs/mixedModels. Last accessed: Sep. 20, 2017.

Clark, R. A. (1991). *Mortality of Arctic grayling captured and released with sport fishing gear*. Alaska Department of Fish and Game, Division of Sport Fish. 36 p.

Claussen, J. (2015, August). The Bhutan Telemetry Project: Tracking Golden Mahaseer in the Manas Watershed. In *145th Annual Meeting of the American Fisheries Society*. AFS, Bethesda, USA.

Cline, T. J., Weidel, B. C., Kitchell, J. F., and Hodgson, J. R. (2012). Growth response of largemouth bass (*Micropterus salmoides*) to catch-and-release angling: a 27-year mark–recapture study. *Canadian Journal of Fisheries and Aquatic Sciences*, *69*(2), 224-230.

Cook, K. V., Lennox, R. J., Hinch, S. G., and Cooke, S. J. (2015). Fish out of water: how much air is too much? *Fisheries*, *40*(9), 452-461.

Cooke, S.J., Philipp, D.P., Dunmall, K.M. and Schreer, J.F. (2001) The influence of terminal tackle on injury, handling time and cardiac disturbance of rock bass. *North American Journal of Fisheries Management, 21*(2), 333-342.

Cooke, S. J., Schreer, J. F., Dunmall, K. M., and Philipp, D. P. (2002). Strategies for quantifying sub-lethal effects of marine catch-and-release angling: insights from novel freshwater applications. In *American Fisheries Society Symposium*. American Fisheries Society, Bethesda, USA. 121-134 pp.

Cooke, S.J. and Cowx, I.G. (2004). The role of recreational fishing in global fish crises. *BioScience*, *54*(9), 857-859.

Cooke, S.J., and Philipp, D.P. (2004). Behaviour and mortality of caught-and-released bonefish (*Albula* spp.) in Bahamian waters with implications for a sustainable recreational fishery. *Biological Conservation, 118*, 599-607.

Cooke, S.J., and Suski, C.D. (2005). Do we need species-specific guidelines for catch-and-release recreational angling to effectively conserve diverse fishery resources? *Biodiversity and Conservation, 14*, 1195-1209.

Cooke, S. J., and Schramm, H. L. (2007). Catch-and-release science and its application to conservation and management of recreational fisheries. *Fisheries Management and Ecology*, *14*(2), 73-79.

Cooke, S.J., and Sneddon, L.U. (2007). Animal welfare perspectives on catch-and-release recreational angling. *Applied Animal Behaviour Science, 104*, 176-198.

Cooke, S. J., Suski, C. D., Ostrand, K. G., Wahl, D. H., and Philipp, D. P. (2007). Physiological and behavioral consequences of long-term artificial selection for vulnerability to recreational angling in a teleost fish. *Physiological and Biochemical Zoology*, 80(5), 480-490.

Cooke, S. J., Hinch, S. G., Donaldson, M. R., Clark, T. D., Eliason, E. J., Crossin, G. T., Raby, G.D., Jeffries, J.M., Lapointe, M., Miller, K., Patterson, D. A., and Farrell, A.P. (2012). Conservation physiology in practice: how physiological knowledge has improved our ability to sustainably manage Pacific salmon during up-river migration. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *367*(1596), 1757-1769.

Cooke, S. J., Paukert, C., and Hogan, Z. (2012). Endangered river fish: factors hindering conservation and restoration. *Endangered Species Research*, *17*(2), 179-191.

Cooke, S. J., Messmer, V., Tobin, A. J., Pratchett, M. S., and Clark, T. D. (2013). Refuge-seeking impairments mirror metabolic recovery following fisheries-related stressors in the Spanish flag snapper (*Lutjanus carponotatus*) on the Great Barrier Reef. *Physiological and Biochemical Zoology*, *87*(1), 136-147.

Cooke, S.J., Raby, G.D., Donaldson, M.R., Hinch, S.G., O'Connor, C.M., Arlinghaus, R., Danylchuk, A.J., Hanson, K.C., Clark, T.D., and Patterson, D.A. (2013). The physiological consequences of catch-and-release angling: perspectives on experimental design, interpretation, extrapolation and relevance to stakeholders. *Fisheries Management and Ecology, 20*, 268-287.

Cooke, S. J., Suski, C. D., Arlinghaus, R., and Danylchuk, A. J. (2013). Voluntary institutions and behaviours as alternatives to formal regulations in recreational fisheries management. *Fish and Fisheries*, *14*(4), 439-457.

Cooke, S.J., Arlinghaus, R., Johnson, B.M., and Cowx, I.G. (2015). Recreational fisheries in inland waters. In J. Craig (Ed.), *Freshwater Fisheries Ecology*. Blackwell Science, Oxford, UK. 449-465 pp.

Cooke, S.J., Arthington, A.H., Bonar, S.A., Bower, S.D., Bunnell, D.B., Entsua-Mensah, R.E.M., Funge-Smith, S., Koehn, J.D., Lester, N.P., Lorenzen, K., Nam, S., Randall, R.G., Venturelli, P., and I.G. Cowx, (2016). Biological Assessment of Inland Fisheries: A Vision for the Future. In: C. Goddard, N. Leonard, W.W. Taylor, D. Bartley, (Eds). Freshwater, Fish, and the Future: Proceedings of the Global Cross-Sectoral Conference. American Fisheries Society, Bethesda, MD.36 pp.

Cooke, S.J., Hogan, Z.S., Butcher, P.A., Stokesbury, M.J.W., Raghavan, R., Gallagher, A.J., Hammerschlag, N., and Danylchuk, A.J. (2016). Angling for endangered fish: Conservation problem or conservation action? *Fish and Fisheries 17*(1), 249-265.

Cooke, S.J., Birnie-Gauvin, K., Lennox, R.J., Taylor, J.J., Rytwinski, T., Rummer, J.L., Franklin, C.E., Bennett, J.R., and Haddaway, N.R. (In Press). How experimental biology and ecology can support evidence-based decision-making in conservation: Avoiding pitfalls and enabling application. *Conservation Physiology, 5(1)*.

Cooke, S.J., Twardek, W., Lennox, R., Zolderdo, A., Bower, S.D., Gutowsky, L.F.G., Danylchuk, A.J., and Beard, T.D. Jr. (In Press). The Nexus of Fun and Nutrition: Recreational Fishing is also about Food. *Fish and Fisheries*. 00:000-000.

Copeland, C., Baker, E., Koehn, J. D., Morris, S. G., and Cowx, I. G. (2017). Motivations of recreational fishers involved in fish habitat management. *Fisheries Management and Ecology*, 24(1), 82-92.

Cowx, I.G. (2002). Recreational Fisheries. In Hart, P.B.J., Reynolds, J.D., (Eds.) Handbook of Fish Biology and Fisheries, vol II. Blackwell Science. Oxford, UK. Pp. 367-390.

Cowx, I.G., Arlinghaus, R. (2008). Recreational Fisheries in the Twenty-First Century: Towards a Code of Conduct. In Aas, Ø. (Ed.), Global Challenges in Recreational Fisheries, vol I. Wiley-Blackwell. Oxford, UK. 338-352 pp.

Cowx, I. G., Arlinghaus, R., and Cooke, S. J. (2010). Harmonizing recreational fisheries and conservation objectives for aquatic biodiversity in inland waters. *Journal of Fish Biology*, *76*(9), 2194-2215.

Crain, C. M., Kroeker, K., and Halpern, B. S. (2008). Interactive and cumulative effects of multiple human stressors in marine systems. *Ecology Letters*, *11*(12), 1304-1315.

Danylchuk, S. E., Danylchuk, A. J., Cooke, S. J., Goldberg, T. L., Koppelman, J., and Philipp, D. P. (2007). Effects of recreational angling on the post-release behavior and predation of bonefish (*Albula vulpes*): the role of equilibrium status at the time of release. *Journal of Experimental Marine Biology and Ecology*, *346*(1), 127-133.

Danylchuk, A. J., and Cooke, S. J. (2011). Engaging the recreational angling community to implement and manage aquatic protected areas. *Conservation Biology*, *25*(3), 458-464.

Davis, M. W. (2010). Fish stress and mortality can be predicted using reflex impairment. *Fish and Fisheries*, *11*(1), 1-11.

Dedual, M., Sague Pla, O., Arlinghaus, R., Clarke, A., Ferter, K., Geertz Hansen, P., Gerdeaux, D., Hames, F., Kennelly, S.J., Kleiven, A.R., Meraner, A., and Ueberschär, B. (2013). Communication between scientists, fishery managers and recreational fishers: lessons learned from a comparative analysis of international case studies. *Fisheries Management and Ecology*, *20*(2-3), 234-246.

De Graaf, G. J., Grainger, R. J., Westlund, L., Willmann, R., Mills, D., Kelleher, K., and Koranteng, K. (2011). The status of routine fishery data collection in Southeast Asia, central America, the South Pacific, and West Africa, with special reference to small-scale fisheries. *ICES Journal of Marine Science: Journal du Conseil*, fsr054.

Dempson, J. B., Furey, G., and Bloom, M. (2002). Effects of catch and release angling on Atlantic salmon, *Salmo salar* L., of the Conne River, Newfoundland. *Fisheries Management and Ecology*, *9*(3), 139-147.

Dillman, D. A., Smyth, J. D., and Christian, L. M. (2014). *Internet, phone, mail, and mixed-mode surveys: the tailored design method*. John Wiley and Sons, New Jersey, USA. 528 p.

Ditton, R.B., Holland, S.M., and Anderson, D.K. (2002). Recreational fishing as tourism. *Fisheries*, 27(3), 17-24.

Donaldson, M.R., Arlinghaus, R., Hanson, K.C. and Cooke, S.J. (2008). Enhancing catch and release science with biotelemetry. *Fish and Fisheries*, *9*(1), 79-105.

Donaldson, M. R., Clark, T. D., Hinch, S. G., Cooke, S. J., Patterson, D. A., Gale, M. K., Frappell, P.B., and Farrell, A. P. (2010). Physiological responses of free-swimming adult Coho salmon to simulated predator and fisheries encounters. *Physiological and Biochemical Zoology*, *83*(6), 973-983.

Donaldson, M. R., Hinch, S. G., Patterson, D. A., Hills, J., Thomas, J. O., Cooke, S. J., Raby, G.D., Thompson, L.A., Robichaud, D., English K.K., and Farrell, A. P. (2011). The consequences of angling, beach seining, and confinement on the physiology, post-release behaviour and survival of adult sockeye salmon during upriver migration. *Fisheries Research*, *108*(1), 133-141.

Dorow, M., Beardmore, B., Haider, W., and Arlinghaus, R. (2009). Using a novel survey technique to predict fisheries stakeholders' support for European eel (*Anguilla anguilla L.*) conservation programs. *Biological Conservation*, *142*(12), 2973-2982.

Donaldson, M. R., Raby, G. D., Nguyen, V. N., Hinch, S. G., Patterson, D. A., Farrell, A. P Rudd, M.A., Thomspon, L.A., O'Connor, C.M., Colotelo, A.H., McConnachie, S.H., Cook, K.V., Robichaud, D., English, K.K., and Cooke, S.J. (2013). Evaluation of a simple technique for recovering fish from capture stress: integrating physiology, biotelemetry, and social science to solve a conservation problem. *Canadian Journal of Fisheries and Aquatic Sciences*, *70*(1), 90-100.

Duda, M. D., and Nobile, J. L. (2010). The fallacy of online surveys: No data are better than bad data. *Human Dimensions of Wildlife*, *15*(1), 55-64.

Eenennaam, J. V., and Doroshov, S. I. (1998). Effects of age and body size on gonadal development of Atlantic sturgeon. *Journal of Fish Biology*, *53*(3), 624-637.

Everard, M., and Kataria, G. (2011). Recreational angling markets to advance the conservation of a reach of the Western Ramganga River, India. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *21*(1), 101-108.

Elmer, L. K., Kelly, L. A., Rivest, S., Steell, S. C., Twardek, W. M., Danylchuk, A. J., Arlinghaus, R., Bennett, J.R., and Cooke, S. J. (2017). Angling into the Future: Ten Commandments for Recreational Fisheries Science, Management, and Stewardship in a Good Anthropocene. *Environmental Management*, 1-11.

Fairclough, D.V., Brown, J.I., Carlish, B.J., Crisafulli, B.M., and Keay, I.S. (2014). Breathing life into fisheries stock assessments with citizen science. *Scientific Reports 4*, 7249.

FAO. (2010). The State of the World's Fisheries and Aquaculture 2010. FAO, Rome, Italy. 197p.

FAO. (2012). Recreational Fisheries. Technical Guidelines for Responsible Fisheries. No. 13. FAO, Rome, Italy. 176 p.

FAO. (2012a). International Guidelines for Securing Sustainable Small-Scale Fisheries. Zero Draft. FAO, Rome, Italy. 31p.

FAO. (2016). The State of the World Fisheries and Aquaculture 2016. Contributing to food security and nutrition for all. FAO, Rome, Italy. 200 p.

Fedler, A. J., and Ditton, R. B. (1994). Understanding angler motivations in fisheries management. *Fisheries*, *19*(4), 6-13.

Feeney, R. G., La Valley, K. J., and Hall-Arber, M. (2010). Assessing stakeholder perspectives on the impacts of a decade of collaborative fisheries research in the Gulf of Maine and Georges Bank. *Marine and Coastal Fisheries*, *2*(1), 205-216.

Flecker, A. S., McIntyre, P. B., Moore, J. W., Anderson, J. T., Taylor, B. W., and Hall Jr, R. O. (2010). Migratory fishes as material and process subsidies in riverine ecosystems. In *American Fisheries Society Symposium*, 73(2), 559-592.

Floyd, M.F., Nicholas, L., Lee, I., Lee, J. and Scott, D. (2006). Social Stratification in Recreational Participation. *Research and Policy Implications*, 28**,** 351-368.

Folt, C. L., Chen, C. Y., Moore, M. V., and Burnaford, J. (1999). Synergism and antagonism among multiple stressors. *Limnology and Oceanography*, *44*(3,2), 864-877.

Freire, K. M., Machado, M. L., and Crepaldi, D. (2012). Overview of inland recreational fisheries in Brazil. *Fisheries*, *37*(11), 484-494.

Freire, K.M.F., Tubino, R.A., Monteiro-Neto, C., Andrade-Tubino, M.F., Belruss, C.G., Tomás, A.R.G., Tutui, S.L.S., Castro, P.M.G., Maruyama, L.S., Catella, A.C., Crepaldi, D.V., Daniel, C.R.A., Machado, M.L., Mendonça, J.T., Moro, P.S., Motta, F.S., Ramires, M., Silva, M.H.C., and Vieira, J.P. (2016). Brazilian recreational fisheries: Current status, challenges and future direction. *Fisheries Management and Ecology*, 23, 276-290.

Fujitani, M., McFall, A., Randler, C., and Arlinghaus, R. (2017). Participatory adaptive management leads to environmental learning outcomes extending beyond the sphere of science. *Science Advances*, *3*(6), e1602516.

Gagne, T. O., Ovitz, K. L., Griffin, L. P., Brownscombe, J. W., Cooke, S. J., and Danylchuk, A. J. (2017). Evaluating the consequences of catch-and-release recreational angling on golden dorado (*Salminus brasiliensis*) in Salta, Argentina. *Fisheries Research*, *186*, 625-633.

Gale, M. K., Hinch, S. G., Cooke, S. J., Donaldson, M. R., Eliason, E. J., Jeffries, K. M., <artins, E.G., and Patterson, D. A. (2014). Observable impairments predict mortality of captured and released sockeye salmon at various temperatures. *Conservation Physiology*, *2*(1).

Garrett, G. P. (2002). Behavioral modification of angling vulnerability in largemouth bass through selective breeding. In *American Fisheries Society Symposium*, American Fisheries Society, Bethesda, USA. 387-392 pp.

Gingerich, A. J., Cooke, S. J., Hanson, K. C., Donaldson, M. R., Hasler, C. T., Suski, C. D., and Arlinghaus, R. (2007). Evaluation of the interactive effects of air exposure duration and water temperature on the condition and survival of angled and released fish. *Fisheries Research*, *86*(2), 169-178.

Godinho, A. L., and Kynard, B. (2009). Migratory fishes of Brazil: life history and fish passage needs. *River Research and Applications*, *25*(6), 702-712.

Granek, E. F., Madin, E. M., Brown, M. A., Figueira, W., Cameron, D. S., Hogan, Z., Kristianson, G., De Villiers, P., Williams, J.E., Post, J., Zahn, S., and Arlinghaus, R. (2008). Engaging recreational fishers in management and conservation: global case studies. *Conservation Biology*, *22*(5), 1125-1134.

Gupta, N., Nautiyal, P., Borgohain, A., Sivakumar, K., Mathur, V. B., and Chadwick, M. A. (2014). Catch-and-release angling as a management tool for freshwater fish conservation in India. *Oryx, 10*(1017), S003060531400078.

Gupta, N., Sivakumar, K., Mathur, V. B., and Chadwick, M. A. (2014). The ‘tiger of Indian rivers’: stakeholders' perspectives on the golden mahseer as a flagship fish species. *Area*, *46*(4), 389-397.

Gupta, N., Bower, S. D., Raghavan, R., Danylchuk, A. J., and Cooke, S. J. (2015). Status of recreational fisheries in India: Development, issues, and opportunities. *Reviews in Fisheries Science and Aquaculture*, *23*(3), 291-301.

Gupta, N., Raghavan, R., Sivakumar, K., Mathur, V., and Pinder, A.C. (2015). Assessing recreational fisheries in an emerging economy: Knowledge, perceptions and attitudes of catch-and-release anglers in India. *Fisheries Research*, *165*, 79-84.

Gutowsky, L.F.G., Harrison, P.M., Landsman, S.J., Power, M., and Cooke, S.J. (2011). Injury and mortality associated with recreational troll capture of bull trout (*Salvelinus confluentus*) in a reservoir in the Kootenay-Rocky Mountain region of British Columbia. *Fisheries Research, 109*, 379-383.

Hall, S.J., Hilborn, R., Andrew, N.L., and E.H. Allison. (2013). Innovations in capture fisheries are an imperative for nutrition security in the developing world. *Proceedings of the National Academy of Sciences*, 110(21), 8393-8398.

Hanson, K.C., Cooke, S.J., Suski, C.D. and Philipp, D.P. (2007). Effects of different angling practices on post-release behaviour of nest-guarding male black bass, *Micropterus* spp. *Fisheries Management and Ecology, 14*, 141–148.

Hartley, T. W., and Robertson, R. A. (2006). Stakeholder engagement, cooperative fisheries research and democratic science: the case of the Northeast Consortium. *Human Ecology Review*, *13*(2), 161.

Hartley, T. W., and Robertson, R. A. (2008). Stakeholder collaboration in fisheries research: integrating knowledge among fishing leaders and science partners in northern New England. *Society and Natural Resources*, *22*(1), 42-55.

Hilborn, R. (1976). Optimal exploitation of multiple stocks by a common fishery: a new methodology. *Journal of the Fisheries Board of Canada*, *33*(1), 1-5.

Hilborn, R., Maguire, J. J., Parma, A. M., and Rosenberg, A. A. (2001). The Precautionary Approach and risk management: can they increase the probability of successes in fishery management? *Canadian Journal of Fisheries and Aquatic Sciences*, *58*(1), 99-107.

Hinch, S.G., Cooke, S.J., Healey, M.C., and A.P. Farrell. 2006. Behavioural physiology of fish migrations: salmon as a model approach. In Farrell, A.P., Brauner, C.J. (Eds.), Fish Physiology Volume 24: Behaviour and Physiology of Fish. Elsevier, Inc. Amsterdam, The Netherlands. 239 – 295 pp.

Hunt, L. M., Sutton, S. G., and Arlinghaus, R. (2013). Illustrating the critical role of human dimensions research for understanding and managing recreational fisheries within a social-ecological system framework. *Fisheries Management and Ecology*, *20*(2-3), 111-124.

Huntington, H. P. (2000). Using traditional ecological knowledge in science: methods and applications. *Ecological Applications*, *10*(5), 1270-1274.

IUCN. (2014). IUCN Red List of Threatened Species. Version 2014.3. <http://www.iucnredlist.org>. Downloaded on 17 November 2014.

IUCN. (2015). The IUCN Red List of Threatened Species. Version 2015-4. <http://www.iucnredlist.org>. Downloaded on 19 November 2015.

IUCN. (2017). *The IUCN Red List of Threatened Species. Version 2017-1*. <http://www.iucnredlist.org>. Downloaded on 12 May 2017.

Jensen, O. P., Gilroy, D. J., Hogan, Z., Allen, B. C., Hrabik, T. R., Weidel, B. C., Chandra, S., and Vander Zanden, M. J. (2009). Evaluating recreational fisheries for an endangered species: a case study of taimen, *Hucho taimen*, in Mongolia. *Canadian Journal of Fisheries and Aquatic Sciences*, *66*(10), 1707-1718.

Jentoft, S., and Chuenpagdee, R. (2009). Fisheries and coastal governance as a wicked problem. *Marine Policy*, *33*(4), 553-560.

Jentoft, S., Pascual-Fernandez, J. J., De la Cruz Modino, R., Gonzalez-Ramallal, M., and Chuenpagdee, R. (2012). What stakeholders think about marine protected areas: case studies from Spain. *Human Ecology*, *40*(2), 185-197.

Jha, B.R. and Rayamajhi, A. (2010). *Tor putitora*. The IUCN Red List of Threatened Species 2010: e.T166645A6254146. http://dx.doi.org/10.2305/IUCN.UK.2010-4.RLTS.T166645A6254146.en. Downloaded on 30 August 2017.

Johnson, B.M., Arlinghaus, R., and Martinez, P.J. (2009). Are we doing all we can to stem the tide of illegal fish stocking? *Fisheries*, 34(8), 389-394.

Kieffer, J. D. (2000). Limits to exhaustive exercise in fish. *Comparative Biochemistry and Physiology Part A: Molecular and Integrative Physiology*, *126*(2), 161-179.

Klefoth, T., Kobler, A. and Arlinghaus, R. (2008). The impact of catch-and-release angling on short-term behaviour and habitat choice of northern pike (*Esox lucius L.*). *Hydrobiologia*, *601*(1), 99-110.

Klefoth, T., Kobler, A., and Arlinghaus, R. (2011). Behavioural and fitness consequences of direct and indirect non-lethal disturbances in a catch-and-release northern pike (*Esox lucius*) fishery. *Knowledge and Management of Aquatic Ecosystems*, (403), 11.

Koontz, T. M., and Thomas, C. W. (2006). What do we know and need to know about the environmental outcomes of collaborative management? *Public Administration Review*, 111-121.

Kothari, U. (2001). Power, knowledge and social control in participatory development. In Kothari, U., and Cooke, B. (Eds.) *Participation: The New Tyranny?*, Zed Books, London, UK, 139-152 pp.

Larkin, P. A. (1977). An epitaph for the concept of maximum sustained yield. *Transactions of the American Fisheries Society*, *106*(1), 1-11.

Lennox, R. J., Brownscombe, J. W., Cooke, S. J., Danylchuk, A. J., Moro, P. S., Sanches, E. A., and Garrone-Neto, D. (2015). Evaluation of catch-and-release angling practices for the fat snook *Centropomus parallelus* in a Brazilian estuary. *Ocean and Coastal Management*, *113*, 1-7.

Lennox, R. J., Uglem, I., Cooke, S. J., Næsje, T. F., Whoriskey, F. G., Havn, T. B., Ulvan, E.M., Solem, O., and Thorstad, E. B. (2015). Does catch-and-release angling alter the behavior and fate of adult Atlantic Salmon during upriver migration? *Transactions of the American Fisheries Society*, *144*(2), 400-409.

Lewin, W.C., Arlinghaus, R., Mehner, T. (2006). Documented and potential biological impacts of recreational fishing: Insights for management and conservation. *Reviews in Fisheries Science,* 14, 305-367.

Likert, R. (1932). A technique for the measurement of attitudes. *Archives of psychology*, 22(140), 5-55.

Lorenzen, K., Cowx, I. G., Entsua-Mensah, R. E. M., Lester, N. P., Koehn, J. D., Randall, R. G., So, N., Bonar, S. A., Bunnell, D. B., Venturelli, P., Bower, S. D. and Cooke S. J. (2016). Stock assessment in inland fisheries: a foundation for sustainable use and conservation. *Reviews in Fish Biology and Fisheries, 26*, 405-440.

Lucas, M.C., Baras, E. (2001). Migration of Freshwater Fishes. Blackwell Scientific Publications, Oxford, UK. 433 p.

Lynch, A.J., I.G. Cowx, E. Fluet-Chouinard, S.M. Glaser, S.C. Phang, T.D. Beard, Jr., S.D. Bower, J.L. Brooks, D.B. Bunnell, J.E. Claussen, S.J. Cooke, Y.-C. Kao, K. Lorenzen, B.J.E. Myers, A.J. Reid, J.J. Taylor, and Youn, S. (In Press). Inland fisheries - invisible but integral to the UN Sustainable Development Agenda for ending poverty by 2030. *Global Environmental Change, 00*, 000-000.

Mackinson, S., Wilson, D. C., Galiay, P., and Deas, B. (2011). Engaging stakeholders in fisheries and marine research. *Marine Policy*, *35*(1), 18-24.

Maggs, J. Q., Mann, B. Q., Potts, W. M., and Dunlop, S. W. (2016). Traditional management strategies fail to arrest a decline in the catch-per-unit-effort of an iconic marine recreational fishery species with evidence of hyperstability. *Fisheries Management and Ecology*, *23*(3-4), 187-199.

Mahon, R. (1997). Does fisheries science serve the needs of managers of small stocks in developing countries. *Canadian Journal of Fisheries and Aquatic Sciences*, *54*(9), 2207-2213.

McClanahan, T. R., Castilla, J. C., White, A. T., and Defeo, O. (2009). Healing small-scale fisheries by facilitating complex socio-ecological systems. *Reviews in Fish Biology and Fisheries*, *19*(1), 33-47.

McLean, M. F., Hanson, K. C., Cooke, S. J., Hinch, S. G., Patterson, D. A., Nettles, T. L., Litvak, M.K., and Crossin, G. T. (2016). Physiological stress response, reflex impairment and delayed mortality of white sturgeon *Acipenser transmontanus* exposed to simulated fisheries stressors. *Conservation physiology*, *4*(1), cow031.

McPhee, D. P., Leadbitter, D., and Skilleter, G. A. (2002). Swallowing the bait: is recreational fishing in Australia ecologically sustainable? *Pacific Conservation Biology*, *8*(1), 40-51.

Meka, J.L. and McCormick, S.D. (2005). Physiological response of wild rainbow trout to angling: impact of angling duration, fish size, body condition and temperature. *Fisheries Research, 72*, 311-322.

Millidine, K. J., Metcalfe, N. B., and Armstrong, J. D. (2008). The use of ventilation frequency as an accurate indicator of metabolic rate in juvenile Atlantic salmon (*Salmo salar*). *Canadian Journal of Fisheries and Aquatic Sciences*, *65*(10), 2081-2087.

Milligan, C. L., Hooke, G. B., and Johnson, C. (2000). Sustained swimming at low velocity following a bout of exhaustive exercise enhances metabolic recovery in rainbow trout. *Journal of Experimental Biology*, *203*(5), 921-926.

Mora, C., Myers, R.A., Coll, M., Libralato, S., Pitcher, T., Sumaila, R., Zeller, D., Watson, R., Gaston, K.J., and Worm, B. (2009). Management effectiveness of the world's marine resources. *PLOS Biology*, *7*(6), e1000131.

Morales, E. M. Q., Lepofsky, D., and Berkes, F. (2017). Ethnobiology and Fisheries: Learning from the Past for the Present. *Journal of Ethnobiology*, *37*(3), 369-379.

Muoneke, M.I. and Childress, W.M. (1994). Hooking mortality: a review for recreational fisheries. *Reviews in Fisheries Science*, *2*(2), 123-156.

Nautiyal, P., Rizvi, A. F., and Dhasmanaa, P. (2008). Life History traits and decadal trends in the growth parameters of Golden Mahseer, *Tor putitora* (Hamilton 1822) from the Himalayan stretch of the Ganga River System. *Turkish Journal of Fisheries and Aquatic Sciences*, *8*, 125-132.

Nautiyal, P. (2014) Review of the art and science of Indian mahseer (game fish) from nineteenth to twentieth century: Road to extinction or conservation? *Proceedings of the National Academy of Science, India, Section B, Biological Sciences, 84*(2), 215-236.

Nelson, T. C., Rosenau, M. L., and Johnston, N. T. (2005). Behavior and survival of wild and hatchery-origin winter steelhead spawners caught and released in a recreational fishery. *North American Journal of Fisheries Management*, *25*(3), 931-943.

Neuendorf, K. A. (2017). *The content analysis guidebook: 2nd edition*. Sage, Los Angeles, USA. 320 p.

Nguyen, V.M., Martins, E.G., Robichaud, D., Raby, G.D., Donaldson, M.R., Lotto, A.G., Willmore, W.G., Patterson, D.A., Farrell, A.P., Hinch, S.G. and Cooke, S.J. (2014). Disentangling the roles of air exposure, gill net injury, and facilitated recovery on the post capture and release mortality and behaviour of adult migratory sockeye salmon (*Oncorhynchus nerka*) in freshwater. *Physiological and Biochemical Zoology* **87**(1), 127-1353.

Nguyen, V. M., Young, N., Hinch, S. G., and Cooke, S. J. (2016). Getting past the blame game: Convergence and divergence in perceived threats to salmon resources among anglers and indigenous fishers in Canada's lower Fraser River. *Ambio*, *45*(5), 591-601.

Nguyen, T. T. (2008). Population structure in the highly fragmented range of *Tor douronensis* (Cyprinidae) in Sarawak, Malaysia revealed by microsatellite DNA markers. *Freshwater Biology*, *53*(5), 924-934.

Nguyen, T. T., Na-Nakorn, U., Sukmanomon, S., and ZiMing, C. (2008). A study on phylogeny and biogeography of mahseer species (*Pisces: Cyprinidae*) using sequences of three mitochondrial DNA gene regions. *Molecular Phylogenetics and Evolution*, *48*(3), 1223-1231.

Newing, H. (2010). *Conducting research in conservation: Social science methods and practice*. Routledge, New York, USA. 400 p.

Øian, H., Aas, Ø., Skår, M., Andersen, O. and Stensland, S. (2017). Rhetoric and hegemony in consumptive wildlife tourism: polarizing sustainability discourses among angling tourism stakeholders. *Journal of Sustainable Tourism*, DOI: 10.1080/09669582.2017.1291650.

Organisation for Economic Co-operation and Development (OECD). (2013). OECD Guidelines on Measuring Subjective Well-being. OECD Publishing, Paris, France. 270 p. Retrieved from: https://www.ncbi.nlm.nih.gov/books/NBK189566/.

Ostrom, E. (2009). A general framework for analyzing sustainability of social-ecological systems. *Science*, *325*(5939), 419-422.

O'Toole, A. C., Danylchuk, A. J., Suski, C. D., and Cooke, S.J. (2010) Consequences of catch-and-release angling on the physiological status, injury, and immediate mortality of great barracuda (*Sphyraena barracuda*) in The Bahamas. *ICES Journal of Marine Science, 67*(8), 1667-1675.

Parkkila, K., Arlinghaus, R., Artell, J., Gentner, M., Haider, W., Aas, Ø., Barton, D., Roth, Eva, and Sipponen, M. (2010). Methodologies for assessing socio-economic benefits of European inland recreational fisheries, EIFAC Occasional Paper No. 46. FAO, Rome, Italy. 112 p.

Pankhurst, N. W., and van Der Kraak, G. (1997). Effects of stress on reproduction and growth of fish. In Iwama, G.K., Sumpter, J., Pickering, A.D., and Schreck, C.B. (Eds.) Fish Stress and Health in Aquaculture. *Society for Experimental Biology Seminar Series 62*, Cambridge University Press, Cambridge, UK, 73–95 pp.

Patterson, D. A., Robinson, K. A., Raby, G. D., Bass, A. L., Houtman, R., Hinch, S. G., and Cooke, S. J. (2017). Guidance to Derive and Update Fishing-Related Incidental Mortality Rates for Pacific Salmon. *DFO Canadian Science Advisory Secretariat Research Document*, *11*. 56 p.

Pauly, D., and Zeller, D. (2016). Global atlas of marine fisheries. *State of the world's oceans series*. (520 pp). Washington: Island Press.

Pawson, M.G., Glenn, H., and Padda, G. (2008). The definition of marine recreational fishing in Europe. *Marine Policy,* 32 (3), 339–350.

Pelicice, F.M., and Agostinho, A. A. (2008). Fish-passage facilities as ecological traps in large neotropical rivers. *Conservation Biology*, *22*(1), 180-188.

Pikitch, E., Santora, C., Babcock, E. A., Bakun, A., Bonfil, R., Conover, D. O., Dayton, P., Doukakis, P., Fluharty, D., Heheman, B., Houde, E.D., Link, J., Livingston, P.A., Mangel, M., Mc Allister, M.K., Pope, J., and Sainsbury, K. (2004). Ecosystem-based fishery management. *Science*, *305*(5682), 346-347.

Pinder, A. C., and Raghavan, R. (2013). Conserving the endangered Mahseers (*Tor* spp.) of India: the positive role of recreational fisheries. *Current Science*, *104*(11), 1472-1475.

Pinder, A. C., Raghavan, R., and Britton, J. R. (2015). The legendary hump-backed mahseer Tor sp. of India's River Cauvery: an endemic fish swimming towards extinction? *Endangered Species Research*, *28*, 11-17.

Pinder, A. C., Raghavan, R., and Britton, J. R. (2015). Efficacy of angler catch data as a population and conservation monitoring tool for the flagship Mahseer fishes (*Tor* spp.) of Southern India. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *25*(6), 829-838.

Plummer, R. and FitzGibbon, J. (2007). Connecting adaptive co-management, social learning, and social capital through theory and practice. In Armitage, D., Berkes. F., and Doubleday, N. (Eds.) Adaptive Co-management: Collaboration, Learning and Multi-level Governance. University of British Columbia Press, Vancouver, Canada. 36–61 pp.

Pollock, K. H., and Pine, W. E. (2007). The design and analysis of field studies to estimate catch-and-release mortality. *Fisheries Management and Ecology*, *14*(2), 123-130.

Pomeroy, R., and Douvere, F. (2008). The engagement of stakeholders in the marine spatial planning process. *Marine Policy*, *32*(5), 816-822.

Post, J.R., Sullivan, M., Cox, S., Lester, N.P., Walters, C.J., Parkinson, E.A., Paul, A.J., Jackson, L., and Shuter, B.J. (2002). Canada's recreational fisheries: The invisible collapse. *Fisheries*, 27(1), 6-17.

Post, J.R. (2013). Resilient recreational fisheries or prone to collapse? A decade of research on the science and management of recreational fisheries. *Fisheries Management and Ecology,* 20(2-3), 99-110.

Potts, W. M., Childs, A. R., Sauer, W. H. H., and Duarte, A. D. C. (2009). Characteristics and economic contribution of a developing recreational fishery in southern Angola. *Fisheries Management and Ecology*, 16(1), 14-20.

Prell, C., Hubacek, K., Quinn, C., and Reed, M. (2008). 'Who's in the network?' When stakeholders influence data analysis. *Systemic Practice and Action Research*, *21*(6), 443-458.

Prince, J. (2010). Rescaling fisheries assessment and management: a generic approach, access rights, change agents, and toolboxes. *Bulletin of Marine Science*, *86*(2), 197-219.

R Core Team (2016). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Rapp, T., Hallermann, J., Cooke, S. J., Hetz, S. K., Wuertz, S., and Arlinghaus, R. (2012). Physiological and behavioural consequences of capture and retention in carp sacks on common carp (*Cyprinus carpio* L.), with implications for catch-and-release recreational fishing. *Fisheries Research*, *125*, 57-68.

Raby, G. D., Donaldson, M. R., Hinch, S. G., Patterson, D. A., Lotto, A. G., Robichaud, D., English, K.K., Willmore, W.G., Farrell, A.P., Davis, M.W and Cooke, S. J. (2012). Validation of reflex indicators for measuring vitality and predicting the delayed mortality of wild Coho salmon bycatch released from fishing gears. *Journal of Applied Ecology*, *49*(1), 90-98.

Raby, G. D., Casselman, M. T., Cooke, S. J., Hinch, S. G., Farrell, A. P., and Clark, T. D. (2016). Aerobic scope increases throughout an ecologically relevant temperature range in Coho salmon. *Journal of Experimental Biology*, *219*(12), 1922-1931.

Raghavan, R. (2011). *Tor khudree*. *The IUCN Red List of Threatened Species 2011*: e.T169609A6653249. http://dx.doi.org/10.2305/IUCN.UK.2011-1.RLTS.T169609A6653249.en. Downloaded on 30 August 2017.

Raghavan, R., Ali, A., Dahanukar, N., and Rosser, A. (2011). Is the Deccan Mahseer, *Tor khudree* (Sykes, 1839)(Pisces: Cyprinidae) fishery in the Western Ghats Hotspot sustainable? A participatory approach to stock assessment. *Fisheries Research*, *110*(1), 29-38.

Reed, M. S., Fraser, E. D., and Dougill, A. J. (2006). An adaptive learning process for developing and applying sustainability indicators with local communities. *Ecological Economics*, *59*(4), 406-418.

Reed, M. S. (2008). Stakeholder participation for environmental management: a literature review. *Biological Conservation*, *141*(10), 2417-2431.

Reed, M. S., Dougill, A. J., and Baker, T. R. (2008). Participatory indicator development: what can ecologists and local communities learn from each other. *Ecological Applications*, *18*(5), 1253-1269.

Reid, K. (2002). Global register of migratory species. *German Federal Agency for Nature Conservation. Project*, *808*(05), 081.

Reid, K. (2004). *Global register of migratory species: from global to regional scales: final report of the RandD-Projekt 808 05 081*. Federal Agency for Nature Conservation.

Rittel, H. W., and Webber, M. M. (1973). Dilemmas in a general theory of planning. *Policy sciences*, *4*(2), 155-169.

Roessig, J. M., Woodley, C. M., Cech, J. J., and Hansen, L. J. (2004). Effects of global climate change on marine and estuarine fishes and fisheries. *Reviews in fish biology and fisheries*, *14*(2), 251-275.

Romero, L. M. (2004). Physiological stress in ecology: lessons from biomedical research. *Trends in Ecology and Evolution, 19.5*, 249-255.

Salz, R. J., and Loomis, D. K. (2005). Recreation specialization and anglers' attitudes towards restricted fishing areas. *Human Dimensions of Wildlife*, *10*(3), 187-199.

Sehgal, K. (1999). Coldwater fish and fisheries in the Western Ghats, India. In Petr, T. (Ed.) *Fish and Fisheries at Higher Altitudes: Asia*, FAO Fisheries Technical Paper 385. FAO, Rome, Italy. 41-64 pp.

Sheaves, M., Baker, R., McLeod, I., Abrantes, K., Wani, J., and Barnett, A. (2016). The conservation status of Niugini black bass: a world-renowned sport fish with an uncertain future. *Fisheries Management and Ecology*, *23*(3-4), 243-252.

Shiffman, D. S., Macdonald, C., Ganz, H. Y., and Hammerschlag, N. (2017). Fishing practices and representations of shark conservation issues among users of a land-based shark angling online forum. *Fisheries Research*, *196*, 13-26.

Shrestha, R.K., Seidl, A.F., and Moraes, A.S. (2002). Value of recreational fishing in the Brazilian Pantanal: a travel cost analysis using count data models. *Ecological Economics,* 42, 289–299.

Silvano, R. A., and Valbo-Jørgensen, J. (2008). Beyond fishermen's tales: contributions of fishers' local ecological knowledge to fish ecology and fisheries management. *Environment, Development and Sustainability*, *10*(5), 657.

Sloan, P. (2009). Redefining stakeholder engagement. *Journal of Corporate Citizenship*, *2009*(36), 25-40.

Skomal, G. B. (2007). Evaluating the physiological and physical consequences of capture on post-release survivorship in large pelagic fishes. *Fisheries Management and Ecology*, *14*(2), 81-89.

Smith, C.L. (1986). The life cycle of fisheries. *Fisheries*, 11(4), 20-25.

Smith, S., and Jepson, M. (1993). Big fish, little fish: Politics and power in the regulation of Florida's marine resources. *Social Problems*, *40*(1), 39-49.

Smith, L. E., Khoa, S. N., and Lorenzen, K. (2005). Livelihood functions of inland fisheries: policy implications in developing countries. *Water Policy*, *7*(4), 359-383.

Smith, J. W., Leahy, J. E., Anderson, D. H., and Davenport, M. A. (2013). Community/agency trust and public involvement in resource planning. *Society and Natural Resources*, *26*(4), 452-471.

Sopinka, N. M., Donaldson, M. R., O'Connor, C. M., Suski, C. D., and Cooke, S. J. (2016). Stress indicators in fish. *Biology of Stress in Fish*, *35*, 406-436.

St. Martin, K., McCay, B. J., Murray, G. D., Johnson, T. R., and Oles, B. (2007). Communities, knowledge and fisheries of the future. *International Journal of Global Environmental Issues*, *7*(2-3), 221-239.

Steyaert, P., Barzman, M., Billaud, J. P., Brives, H., Hubert, B., Ollivier, G., and Roche, B. (2007). The role of knowledge and research in facilitating social learning among stakeholders in natural resources management in the French Atlantic coastal wetlands. *Environmental Science and Policy*, *10*(6), 537-550.

Stoot, L.J., Cairns, N.A., Cull, F., Taylor, J.J., Jeffrey, J.D., Morin, F., Mandelman, J.W., Clark, T.D., and Cooke, S.J. (2014). Use of portable blood physiology point-of-care devices for basic and applied research on vertebrates – a review. *Conservation Physiology, 2,* cou011.

Suski, C.D., Cooke, S.J., Danylchuk, A.J., O'connor, C.M., Gravel, M.A., Redpath, T., Hanson, K.C., Gingerich, A.J., Murchie, K.J., Danylchuk, S.E., Koppelman, J.B., Goldberg, T.L. (2007). Physiological disturbance and recovery dynamics of bonefish (*Albula vulpes*), a tropical marine fish, in response to variable exercise and exposure to air. *Comparative Biochemistry and Physiology*, *Part A 148*, 664-673.

Sutherland, W. J. (1998). The importance of behavioural studies in conservation biology. *Animal Behaviour, 56*(4), 801-809.

Sutton, S. G., and Ditton, R. B. (2001). Understanding catch-and-release behavior among US Atlantic bluefin tuna anglers. *Human Dimensions of Wildlife*, *6*(1), 49-66.

Sugunan, V.V. (2010). Inland fisheries resource enhancement and conservation in India. In Weimin, M., De Silva, S. Davy, B. (Eds.) *Inland Fisheries Resource Enhancement and Conservation in Asia.* FAO Regional Office for Asia and the Pacific, Bangkok, Thailand. 35-60 pp.

Swaisgood, R. R. (2007). Current status and future directions of applied behavioral research for animal welfare and conservation. *Applied Animal Behaviour Science, 102*(3), 139-162.

Tacon, A.C.J., and Metian, M. (2009). Fishing for feed or fishing for food: increasing global competition for small pelagic forage fish. *AMBIO: A Journal of the Human Environment*, 38(6), 294-302.

Taylor, R. G., Whittington, J. A., and Haymans, D. E. (2001). Catch-and-release mortality rates of common snook in Florida. *North American Journal of Fisheries Management*, *21*(1), 70-75.

Thorstad, E.B., Næsje, T.F., Fiske, P. and Finstad, B. (2003). Effects of hook and release on Atlantic salmon in the River Alta, northern Norway. *Fisheries Research*, *60*(2), 293-307.

Thorstad, E.B., Hay, C.J., Næsje, T.F., Chanda, B. and Økland, F. (2004). Effects of catch-and-release angling on large cichlids in the subtropical Zambezi River. *Fisheries Research*, *69*(1), 141-144.

Thorstad, E. B., Næsje, T. F., and Leinan, I. (2007). Long-term effects of catch-and-release angling on ascending Atlantic salmon during different stages of spawning migration. *Fisheries Research*, *85*(3), 316-320.

Thomson, C.J. (1991). Effects of the avidity bias on survey estimates of fishing effort and economic value. *American Fisheries Society Symposium, 12*, 356-366.

Tufts, B. L., Holden, J., and DeMille, M. (2015). Benefits arising from sustainable use of North America's fishery resources: economic and conservation impacts of recreational angling. *International Journal of Environmental Studies*, *72*(5), 850-868.

United Nations (UN). (2006). Standard country or Area Codes for Statistical Use. Series M, No. 49, Rev. 4, United Nations Publication, Sales No. M.98.XVII.9. Retrieved from: http://unstats.un.org/unsd/methods/m49/m49regin.htm.

United Nations (UN). (2015). Human Development Report, 'Work for Human Development'. United Nations Development Program. United Nations, New York, USA. 288 p.

United Nations (UN). (2017). Western Economic Situations and Prospects (WESP) Report. United Nations Publication, Sales No. E.17.II.C.2. United Nations, New York, USA. 222 p.

Venables, W.N., and Ripley, B.D. (2002). Modern Applied Statistics with S, Fourth Edition. Springer, New York, USA. 498 p.

Venturelli, P. A., Hyder, K., and Skov, C. (2017). Angler apps as a source of recreational fisheries data: opportunities, challenges and proposed standards. *Fish and Fisheries*, *18*(3), 578-595.

Voyer, M., Barclay, K., McIlgorm, A., and Mazur, N. (2017). Connections or conflict? A social and economic analysis of the interconnections between the professional fishing industry, recreational fishing and marine tourism in coastal communities in NSW, Australia. *Marine Policy*, *76*, 114-121.

Walters, C., and Martell, S. J. (2002). Stock assessment needs for sustainable fisheries management. *Bulletin of Marine Science*, *70*(2), 629-638.

Walters, C. J. (2007). Is adaptive management helping to solve fisheries problems?. *AMBIO: A Journal of the Human Environment*, *36*(4), 304-307.

Ward, H. G., Allen, M. S., Camp, E. V., Cole, N., Hunt, L. M., Matthias, B., Post, J.R., Wilson, K., and Arlinghaus, R. (2016). Understanding and managing social–ecological feedbacks in spatially structured recreational fisheries: The overlooked behavioral dimension. *Fisheries*, *41*(9), 524-535.

Welcomme, R.L. (2001) *Inland Fisheries: Ecology and Management*. Blackwell, Oxford, UK. 350 p.

Weston, C., Gandell, T., Beauchamp, J., McAlpine, L., Wiseman, C., and Beauchamp, C. (2001). Analyzing interview data: The development and evolution of a coding system. *Qualitative sociology*, *24*(3), 381-400.

White, A. J., Schreer, J. F., and Cooke, S. J. (2008). Behavioral and physiological responses of the congeneric largemouth (*Micropterus salmoides*) and smallmouth bass (*M. dolomieu*) to various exercise and air exposure durations. *Fisheries Research*, *89*(1), 9-16.

Williams, G. J. (2011), Data Mining with Rattle and R: The Art of Excavating Data for Knowledge Discovery, Use R! (374 pp). New York: Springer.

Wood, A. L., Butler, J. R., Sheaves, M., and Wani, J. (2013). Sport fisheries: Opportunities and challenges for diversifying coastal livelihoods in the Pacific. *Marine Policy*, *42*, 305-314.

Wood, C. M., Turner, J. D., and Graham, M. S. (1983). Why do fish die after severe exercise? *Journal of Fish Biology*, *22*(2), 189-201.

Wood, C. M. (1991). Acid-base and ion balance, metabolism, and their interactions, after exhaustive exercise in fish. *Journal of Experimental Biology*, *160*(1), 285-308.

World Bank. (2012). Hidden Harvest: The global contribution of capture fisheries. Report # 66469-GLB. World Bank. Washington, D.C., USA. 69p.

WWF- India. (2013). Mahseer Conservation in India: Status, Challenges and the Way Forward. P. Nautiyal, S. Babu and S. Behera (Eds.). WWF-India, New Delhi, India, 38p.

Yergey, M. E., Grothues, T. M., Able, K. W., Crawford, C., and DeCristofer, K. (2012). Evaluating discard mortality of summer flounder (*Paralichthys dentatus*) in the commercial trawl fishery: Developing acoustic telemetry techniques. *Fisheries Research, 115*, 72-81.

Yochum, N., Starr, R. M., and Wendt, D. E. (2011). Utilizing fishermen knowledge and expertise: keys to success for collaborative fisheries research. *Fisheries*, *36*(12), 593-605.

Ziberna, A., Kejzar, N., and Golob, P. (2004). A comparison of different approaches to hierarchical clustering of ordinal data. *Metodoloski zvezki*, 1(1), 57.

Zuur A., Ieno E.N., Walker N., Saveliev A.A. and Smith G.M. (2009) 'Mixed Effects Models and Extensions with R'. In: *Statistics for Biology and Health*, Eds M. Gail, K. Krickeberg, J.M. Samet, A. Tsiatis, and W. Wong. Springer, NY, USA, 574p.