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Casting for Knowledge and Landing Understanding

Exploring the management of Swedish recreational fisheries as social-ecological systems

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Abstract

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The successful management of recreational fisheries must balance ecological, and social goals; select from and implement a range of management tools; operate under often complex governance structures; and contend with diverse human stakeholders' expectations, desires, and actual behaviour in response to management activities. This complexity also means that there are many knowledge and research gaps regarding the information needed to meet the requirements of specific fisheries. This thesis explores Swedish recreational fisheries as social-ecological systems to help close these gaps, and improve their future management.

The sea trout (*Salmo trutta*) fishery around the island of Gotland provides context for investigating the human and ecological dimensions of catch-and-release (C&R), and stock level connections between angler expectations, catches, and spawning returns. This case study first identifies key motivations to retain or release sea trout of legal size, and factors anglers think are important for successful C&R. Then determines which angler-related, fish-related, or environmental factors impact stress levels and injuries for sea trout. Further, it identifies the potential for small changes in anglers harvest preferences to significantly impact mortality rates for an important segment of the spawning population. Taken together these outcomes identify knowledge and behavioural gaps that influence the successful application of C&R in this fishery, and that could affect the achievement of fishery management goals.

Several opportunities to improve the transfer of information between stakeholder groups in Swedish recreational fisheries are illuminated through an assessment of how best practices for C&R are communicated to anglers, and an evaluation of potential biases generated when collecting data through angler surveys. Communication from freshwater fishery managers to fishing license buyers is deficient in the quality and quantity of information on best practices for C&R. In addition, this is notably poorer for certain fisheries and target species that have very high rates of C&R. In the opposite direction, the collection of information from anglers is also challenging, as common sampling techniques and the grouping of survey responses in recreational fisheries can introduce significant biases that impact how data can be interpreted. These include psychological dimensions of fishing experiences that connect angler motivations and behaviours to fishery management structures.

This thesis contributes to the knowledge and discussion about sustainably managing recreational fisheries, but the methods to apply this information to existing governance structures and induce positive behavioural change in diverse populations of anglers require further development.

Keywords: Recreational Fisheries, Fisheries Management, Catch & Release, Social-ecological System, Angler Behaviour, Fish Behaviour, Fish Welfare, Stakeholder Engagement

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To the little fish and the family that said it would be stupid not to do this.

List of Papers

This thesis is based on the following papers, which are referred to in the text by their Roman numerals.

I. **Blyth, S.**, Rönnbäck, P. 2022. To eat or not to eat, coastal sea trout anglers' motivations and perceptions of best practices for catch and release. *Fisheries Research*. 254:1-11. DOI: 10.1016/j.fishres.2022.106412

II. **Blyth, S.**, Bower, S. 2022. After the spawn and on the hook, sea trout Salmo trutta biophysical responses to different components of catch and release in a coastal fishery. *Journal of Fish Biology*. 101:1– 14. DOI: 10.1111/jfb.15108

III. **Blyth, S.**, Stensland, S., Rönnbäck, P. 2024. Imagination, reality, and reproduction: Comparing the expectations of coastal sea trout anglers with real catches and sea trout spawning activity. *Submitted*.

IV. Björkvik, E., **Blyth, S**., Blicharska, M., Danley, B., Rönnbäck, P. 2023. Informing obligations: Best practice information for catch-and-release in Swedish local recreational fisheries management. *Fisheries Management and Ecology* 30:310-322. DOI: 10.1111/fme.12622

V. **Blyth, S**., van den Heuvel, L., Blicharska, M., Bergström, U., Ovegård, M., Rönnbäck, P., Sundblad, G. 2024. Beyond asking the right questions: Accounting for biases in a recreational fishery survey. *Submitted*.

The contribution of Samuel Allan Blyth to the papers included in this thesis was as follows:

In Papers I, II, and III, the author of this thesis initiated the studies, had the main responsibility for the conception and design of the work, had the main responsibility for fieldwork, data gathering and analysis, and writing of the papers.

In Paper IV, the author made substantial contributions to the conception and design of the work, data analysis and interpretation, and writing of the paper.

In Paper V, the author was involved in the conception and planning of data collection, had the main responsibility for analysis, and contributed substantially to the structuring and writing of the paper.

Additional Work

The author additionally contributed to the following relevant publications, which are not part of this thesis:

Magnusson, K., Kagervall, A., Dannewitz, J., **Blyth, S.**, 2022. Havsöring på Gotland – beståndsstatus och effekter av olika fiskeregleringar. Drottningholm, Sweden: Sveriges lantbruksuniversitet (SLU), Institutionen för akvatiska resurser. 1-27.

van den Heuvel, L., Blicharska, M., **Blyth, S.**, Rönnbäck, P., 2020. Catch reporting in recreational fishing: Swedish anglers' attitudes and preferences, and the effect of social factors. Fisheries Research. 223:105444. DOI:10.1016/j.fishres.2019.105444

Contents

Abbreviations

C&R	catch-and-release
NGO	non-government organization
RAMP	reflex action mortality predictors
SES	social-ecological system

1. Introduction

1.1 Research Rationale

Recreational fishing, often using a rod and line, is a globally important outdoor activity that links hundreds of millions of people to marine and freshwater ecosystems (Arlinghaus et al., 2020). Recreational fisheries are generally defined as not contributing to sale or trade in markets (i.e., commercial fisheries), or constituting individuals' primary dietary needs (i.e., subsistence fisheries) (FAO, 2012). Yet, they also represent hundreds of billions of dollars worth of economic activity on an annual basis (Arlinghaus et al., 2020), and important contributions to meeting the nutritional needs of individuals and communities (Cooke et al., 2018). The sustained utilization of these benefits requires the responsible management and governance of recreational fisheries, which respects their biological and social limits. Recreational fisheries comprise a complex range of interactions between diverse human and biological dimensions, in this context a social-ecological systems (SES, defined and explored in Section 2.2) approach provides a useful framework to understand them and to design appropriate management (Arlinghaus et al., 2017; Hunt et al., 2013).

The decision making landscape for managing recreational fisheries faces many limitations regarding the quality and quantity of data available, and a host of research questions are yet to be answered in order to identify and address the complex challenges facing these dynamic SES (Holder et al., 2020). Biological data is often limited to extrapolations from relatively small samples of populations and communities that are dispersed across management units, and are further influenced by a range of other factors that may not currently be measured or accounted for, such as, resilience with respect to climate change (Holder et al., 2020), feedback loops generated by habitat enhancement (Chong et al., 2023), or simply the lack of baseline data and sufficient information to make assessments (Pilling et al., 2009; Rick and Lockwood, 2013). Human dimensions data are also commonly missing for many of the recreational fisheries and moreover they are often subject to additional influences from factors such as sampling (Griffiths et al., 2013), non-response (Cavari and Freedman, 2018), avidity (Thomson, 1991), and recall (Connelly et al., 2000; Lewin et al., 2021) biases, which have the potential to shape the utility of what data is gathered through different types of angler surveys.

The topic of catch-and-release (C&R, defined and explored in Section 2.1) provides several opportunities to apply a mixed methods research approach to

better understand some of the challenges to recreational fisheries management, and some of the solutions to those challenges (Holder et al., 2020). As an explicit part of many common regulations (i.e., size limits) and a voluntary behaviour, C&R provides an interesting lens to explore how anglers choose to behave, and the resulting impacts of that behaviour on fisheries. There has been a long established need to develop species specific guidelines for how C&R is performed that account for the diversity of fishing practices and biological needs of different species (Cooke and Suski, 2005). Yet hundreds of species targeted by anglers and a plethora of fishing situations remain for which C&R best practices are not well understood or communicated (Brownscombe et al., 2019a; Donaldson et al., 2011; Holder et al., 2020). Further, there are many opportunities for research to improve understanding of the human dimensions of why and how people perform C&R (Cooke et al., 2017; Holder et al., 2020), as the diversity of biological responses to particular management tools are mirrored by a wide range of human factors (Hunt et al., 2021; Johnston et al., 2010).

Applying the SES framework beyond specific management tools and looking at the broad set of interactions that occur across this system is important to ensure the pursuit of desirable and sustainable management, and that management actions are not working at crossed purposes (Arlinghaus et al., 2017; Ostrom, 2009). This extends to the evaluation of governance structures, how authorities communicate the information necessary for resource users to operate within the boundaries of the system, and contribute to functioning management tools. Research has started to address this with the topic of C&R (Pelletier et al., 2007; Sims and Danylchuk, 2017), however relatively limited knowledge is available for different countries, cultural contexts, and under different management structures. Identifying how regulations and management tools laid out by fisheries managers may influence the norms, attitudes, and intentions of anglers is an important step in determining how these are translated into anglers' actions and outcomes that impact the entire SES (Heberlein, 2012; Hunt et al., 2013). Similar pathways and feedback loops are present on the ecological side of the SES and must be accounted for to understand the eventual outcomes of any management decisions and where actions must be adapted to ensure the sustainability of the system (Arlinghaus et al., 2017; Innes-Gold et al., 2021). As an example, if new regulations are implemented in response to a declining stock trend how will anglers react and can socially desirable fishery outcomes be maintained, will the stock and ecosystem respond as expected, and how will management adapt to the new characteristics of the system? Research efforts to better understand complex, dynamic, and evolving SESs must also be accompanied by critical evaluation of how managers and other stakeholders are able to interpret the information that is available to them. This is necessary to understand both human and biological dimensions of the fishery, and to effectively address their needs.

Improving the quality and quantity of information available across the recreational fisheries SES should create opportunities to enhance the positive effects of management to the benefit of resource users, resource units, and the resilience of the system as a whole. Although access to more information does not guarantee that all recreational fisheries stakeholders will make the right decisions for the sustainability of the system, better understanding of the SES's individual components and their relationships with each other should clarify visions of what is being aimed at, and make it harder to make bad decisions.

1.2 Aims and Research Objectives

The aim of this thesis is to explore recreational fisheries management in Sweden with a SES perspective, primarily by using the tool C&R as a lens to identify challenges and opportunities for achieving fisheries management goals. It covers topics starting from the knowledge and behaviour of anglers, the impact of C&R on individual fish, and angler preferences in a fishery specific context; and leading to explorations of the information landscape around C&R best practices at the national scale, and of the diversity of angler characteristics. Taken together these topics address several of the "100 most important research questions in the field of recreational fisheries" identified by Holder et al. (2020), and are intended to contribute to the practical goals of informing and improving recreational fisheries management.

The specific objectives of this thesis are:

- **Objective A** – To explore the fishery specific application of C&R using a SES perspective to identify opportunities for improving the function of this fishery management tool. Increasing understanding of anglers' knowledge, motivations, and behaviours with respect to C&R (**Paper I**) and evaluating the responses of individual fish to several aspects of C&R, and to identify key gaps in angler knowledge and behaviour with respect to which C&R best practices have the greatest impact on stress in fish during angling (**Paper II**).
- **Objective B** – To evaluate relationships among angler expectations, harvest preferences, the characteristics of actual catches, and the characteristics of the spawning population; and investigate possible outcomes and feedback from voluntary and involuntary changes to harvests (**Paper III**).
- **Objective C** – To investigate aspects of the information landscape that provide fisheries management and governance with data on resource users, as well as how management goals and objectives are communicated to anglers. Examining the role of angler heterogeneity with respect to different forms of sampling biases (e.g., selection, non-response, and avidity) when collecting human dimensions data though

surveys (**Paper V**), and evaluating the communication of best practices for C&R across multiple privately managed fisheries at the national scale (**Paper IV**).

1.3 Outline of the Thesis

This thesis is based on **Papers I-V**, which are presented as Chapters 7-11. The current chapter provides an overview of the project and the unifying aim of the papers and research. Chapter 2 explains the broader background and context for the thesis by briefly defining recreational fishing, providing a description of C&R, then outlining and discussing the structure of the SES encompassing recreational fishing and which aspects of the system the individual papers illuminate. Chapter 3 provides a brief explanation and reflection on some of the methodologies used in **Papers I-V**. Chapter 4 summarizes the findings of **Papers I-III**, focusing on the human and biological aspects of C&R within a single fishery, and **Papers IV** and **V**, which focus on the information landscape that informs anglers about best practices for C&R, and how data on the human dimensions of recreational fisheries is collected by researchers and fishery managers. Chapter 5 discusses some of the most important connections between the findings of **Papers I-V**, and provides a look forward on future avenues for research that would improve our understanding of these SESs and support robust and sustainable recreational fisheries management in Sweden. Chapter 6 is an overview of the conclusions drawn from this thesis to illuminate the relationships occurring within the complex web of SES of recreational fisheries.

2. Background

The first section of this chapter defines recreational fishing and presents several of the factors that must be considered for the sustainable management of recreational fisheries. This section then introduces C&R as a management tool commonly used in recreational fisheries. C&R is used as a lens for exploring the social and ecological dimensions of recreational fisheries in **Papers I, II** and **IV**, and is a peripheral component of **Papers III** and **V**. The second section of this chapter presents and discusses Swedish recreational fisheries as social-ecological systems, highlighting the key areas and interactions that are illuminated by **Papers I-V**. References to these papers are used throughout this section to highlight where findings can be applied to improve understanding across the recreational fisheries SES.

2.1 Defining Recreational Fishing, and Catch-and-Release

Recreational Fishing

Fishing has been an important component of human existence for thousands of years (O'Connor et al., 2011; Sahrhage and Lundbeck, 2012). The capture of fish and shellfish continues to provide a key source of protein for much of the world's population. Additionally, fishing, and the sale of marine and freshwater resources provide income to millions of people (Arlinghaus et al., 2002; Hilborn et al., 2003a; Jennings et al., 2009). The importance of the benefits that humans get from fisheries resources in the past and in the present are reflected in a long history of awareness that harvest, including recreational harvest, can deplete fish stocks and in the documented implementation of fishing regulations in Europe during the Middle Ages (Locker, 2014; Policansky, 2002).

The simple definition of recreational fishing is fishing where the primary motivation is neither financial nor subsistence (FAO, 2012). This means that recreational fishers are not fishing with the intention of selling what they catch and they are not fishing to provide a primary source of nutrition or to meet another basic need. Although income and basic nutrition are not the primary motivations to catch fish in a recreational fishery, recreational fishing is a

multi-billion dollar industry and the consumption of recreationally caught fish can be very important (Arlinghaus et al., 2019; Cooke et al., 2018).

People most commonly associate recreational fishing with various forms of angling (fishing with a hook and line), and this is representative of how most people engage in these activities, as well as how fishing is commonly referred to in this thesis (FAO, 2012). However, recreational fishing is not restricted to angling and can include a wide range of methods including, but not limited to, spear fishing, net fishing, fish traps, bow fishing, noodling (catching fish with your hands), and more (Cooke et al., 2018; FAO, 2012).

Recreational fishing is not limited to any particular species, group of species, or ecosystem. The targets and locations of these activities are highly diverse (FAO, 2012), with examples ranging from ice fishing for arctic char in frozen mountain lakes, to free diving for spiny lobsters in tropical seas; or from angling for carp in a park pond or canal in a major city, to pursuing species found in undisturbed watersheds deep in the rainforest.

At a global level, recreational fisheries represent important networks of social-ecological interactions. For humans these networks and activities can produce substantial economic and social benefits, as indicated by the generation of billions of dollars in economic activity (Arlinghaus et al., 2019; FAO, 2012), and the host of factors that contribute to satisfaction for people who fish (Birdsong et al., 2021). At the same time these fishing activities can cause many negative impacts for fish and the ecosystems that support them, which can include effects on the welfare and behaviour of individual fish (Browman et al., 2018; Malone and Polivka, 2022), influencing fish numbers at the stock level (Radford et al., 2018), and driving ecosystem level changes (Weir et al., 2022)(for further details see section 2.1). However, participation in fishing activities also has the potential to build awareness and strong connections between humans and natural systems, which can drive participation in conservation or stewardship activities and the adoption of management tools to mitigate the negative impacts of fishing activities (Granek et al., 2008; Shephard et al., 2022). Recreational fishing and harvests can be used to structure fish communities to meet the desires of anglers and managers for greater fish abundance, growth rates, and catch rates (Sass and Shaw, 2020).

While the responsible use of recreational fisheries has the potential to provide many benefits to both humans and natural systems, accessing these benefits in the long term requires a conscious effort to balance trade-offs within and among the complex social and ecological components of fisheries. Looking at smaller segments or components of this complicated web of social and ecological interactions can make it easier, and can be crucial in many cases, to identify particular challenges to sustainable fisheries use, and what tools or strategies are needed to overcome these challenges. This segmentation can be critical in many cases where fishery-specific circumstances dictate the available paths to sustainability, and blanket solutions are unlikely to achieve the desired outcomes. Broadly, fisheries related impacts, management goals, and

the tools used to reach them have historically been divided into two categories based on separate human and nature sides of this social-ecological interaction (Arlinghaus et al., 2013). One category or lens has focused on ecological dimensions addressing what happens to fish, and the ecosystems in which they live. The other side was focused on the social or human dimensions that drive the decisions that people make about fishing and the outcomes that they hope to achieve (Cooke et al., 2017; Fenichel et al., 2013; Hunt et al., 2013). This division can be useful to identify individual issues or goals for fisheries management, and some of the pathways to address them. However, sustainable fisheries management must consider all of these components as linked and interdependent aspects of complex social-ecological systems (Bodin et al., 2014; Hunt et al., 2013; Lewin et al., 2006; Ostrom, 2009). This is made even more challenging by the fact that each species, ecosystem, and group of recreational fishers have different needs and different impacts on one another (Mora et al., 2009). This means that there is no single method to develop the management of all fisheries and achieve sustained success (Cowx et al., 2010; Holder et al., 2020). Desired outcomes, and the management plans and tools needed to reach those outcomes must be tailored to meet the needs of individual recreational fisheries (Cooke and Suski, 2005).

Catch and Release

Many of the most commonly used management tools in recreational fisheries are predicated on the idea that not all of the fish that are caught can or should be harvested, and that returning fish alive to the water through C&R can contribute to fishery sustainability. These tools can include size-based regulations that protect fish until they are large enough to reproduce, protect particularly large and/or female fish in a population, as well as seasonal restrictions on the harvest of particular species (Policansky, 2002). At the same time many anglers choose to practice voluntary C&R as a means to continue enjoying the non-harvest benefits of recreational fishing (e.g., social, nature experience, relaxation), while reducing some of the impacts that the activity has on fish stocks (Arlinghaus et al., 2007).

Achieving the goal of a successful release (i.e., catching and then releasing a fish in manner that minimizes negative impacts on fish health and behaviour) is dependent on a combination of social, biotic, and abiotic variables including the fisher's skill and intentions, gear choice, the species of fish, and a range of environmental conditions (Arlinghaus et al., 2007). Although a 100% chance of survival cannot be guaranteed by any form of C&R, in ideal situations the risk of mortality can be less than 1%, conversely, in the worst situations mortality can be >90% (Bartholomew and Bohnsack, 2005; Muoneke and Childress, 1994). There are also risks of sublethal impacts from stress and injury to the long-term behaviour, reproduction, and well-being of released fish,

which are well-known for some fisheries, but poorly understood in many others (Arlinghaus et al., 2007; Holder et al., 2020). Such variation makes the decisions of anglers or management case specific whether to apply C&R as a tool, and for it to be successful (Arlinghaus et al., 2007; Bartholomew and Bohnsack, 2005; Muoneke and Childress, 1994). Human dimensions drive patterns in which species are targeted and harvested (Cooke et al., 2018; Ferter et al., 2013), and can impact the outcomes for released fish through gear selection, handling practices, and the physical context where fishing occurs (Cooke et al., 2017; Lizée et al., 2018). At the same time ecological dimensions determine which of these components are actually the most important in each fishing situation, and change based on factors such as location, season, and species (Brownscombe et al., 2017; Logan et al., 2019). Some factors consistently reduce risks of mortality and sub-lethal effects in most release situations (e.g., limiting air exposure, avoiding contact with dry surfaces, and minimizing handling time), but the relative importance of each of these variables can vary greatly based on the circumstances of the human and ecological dimensions where it is employed (Brownscombe et al., 2017; Thorstad et al., 2003). This suggests the need for fishery and species specific regulations and recommendations for C&R best practices, and the appropriate social and ecological research to support their validity and acceptance by fishers (Cooke and Suski, 2005). Thus, the successful application of C&R in fisheries management requires a biologically sound foundation to how C&R is performed, as well as angler awareness of how to handle and release fish properly, and their motivation to do so.

All fishing involves either the deliberate ending of another organism's life or the risk that death occurs as an unintended result of the activity, and in this context the activity should be given moral and ethical consideration. From some perspectives C&R is an unethical activity that is just wasteful playing with food, or torturing animals for human entertainment (Aas et al., 2007; Øian et al., 2017). However, although it is impossible to guarantee that 100% of released fish will survive, it would be easy to ensure the death of fish that are retained and the subsequent negative impacts to the species' population without C&R (Jensen et al., 2009). If fish were given the choice between certain death and only a chance of death, it makes C&R seem like the more favourable option once hooked. In different countries, there are distinct ethical views on C&R, which impact how this management tool is used. For example, British Columbia, Canada is host to steelhead trout (*Oncorhynchus mykiss*) fisheries that are exclusively C&R as a result of social norms and government policies regarding the management of these stocks (Pitman et al., 2018a). While in Germany every fish that is caught, which is not covered by size limits, seasonal restrictions, or protected species status, is killed as a result of the social norms and legal situation created by the country's Animal Protection Act (Arlinghaus, 2007). This removes the opportunity to release those fish that are most likely to survive the process of being caught in cases where their

harvest is not needed to meet human nutritional demands or other fisheries management goals.

Ethical discussions of the use of C&R as a management tool are often tied to the concepts of utility and intrinsic value. Under a wholly anthropocentric perspective fish only have value in situations where they are useful for humans, such as providing food or entertainment. The intrinsic values of fish or the ecosystems that they live in can be recognized by extending moral domain to these entities. However, this intrinsic value may not be enough to ensure that humans take the necessary actions to conserve these other entities. Studies show that personal benefit is a greater motivation for supporting environmental conservation than the intrinsic values of nature (Asah and Blahna, 2012; Grammatikopoulou et al., 2016; Wallin et al., 2013). At the same time, the intrinsic value of the fish and their utility as a resource for humans do not have to be mutually exclusive (Arlinghaus et al., 2007). As a tool, C&R allows people to engage in fisheries and receive personal benefit from them in a manner that also reduces some of the negative impacts of obtaining these benefits, which could lead to greater benefits to the environment beyond the level of the individual fish through increased motivations for stewardship and care for natural systems (Cooke et al., 2016; Shephard et al., 2022).

Aside from the ethical and moral arguments, there is general agreement among researchers that if fishing is to occur as a means of providing food or pleasure for humans, then C&R is required in some circumstances (Arlinghaus et al., 2007). Consensus on the positive role of C&R is particularly strong if mortality is negligible in cases where there are accidental catches of: threatened or endangered species, individuals that are too small or outside size limits, or fish that are otherwise protected, such as seasonal vulnerability during spawning (Arlinghaus et al., 2007; Cooke et al., 2016; Granek et al., 2008). If recreational fishing continues to have roles for C&R then future fisheries management requires an understanding of best practices for C&R and how recreational anglers adopt them to ensure low rates of mortality and sublethal impacts for released fish.

Research has the potential to help identify what social and ecological factors are key to attaining fisheries management goals through the use of C&R and other tools (Holder et al., 2020). As a specific topic of inquiry C&R can be used to examine the function of existing regulations that rely on successful C&R to function, as well as to explore voluntary C&R as an indicator of anglers' motivations and activity to predict their behaviour in response to future management scenarios (**Papers I** and **III**). Investigating the information landscape around C&R best practices and regulations to better understand communication between various stakeholders and resource users can provide insights that are relevant to a number of resource management regimes (**Paper IV**). Taken together this information can be used to shape regulations that better suit fishery needs, as well as guide voluntary institutions and behaviours

that contribute to conservation and responsible resource use (Cooke and Suski, 2005; Cooke et al., 2013b).

2.2 The Social-Ecological System of Recreational Fisheries Management

Addressing natural resource management issues requires a social-ecological system approach that includes the biological thresholds that physically define a system's productive capacity, as well as the human dimensions of resource use, both of which may be in constant states of fluctuation (Berkes and Folke, 1998; Ostrom, 2007). Recreational fisheries have been clearly established as examples that can be explored and understood as complex and adaptive social-ecological systems (Arlinghaus et al., 2017; Hunt et al., 2013; Ostrom, 2009; Ward et al., 2016). However, the study of various fishery management tools has traditionally focused on either the social or the ecological side of the system, rather than investigating their many diverse and complex interactions (Fenichel et al., 2013; Hunt et al., 2013). Achieving desirable conservation outcomes requires assessment of and accounting for the explicit impacts and interdependencies between the human and the ecological dimensions of these systems (Bodin et al., 2014).

At a fishery-specific level, understanding of the various components of the social-ecological system provides a baseline against which changes may be measured and a framework on which specific goals may be targeted (Figure 1). Changes to governance and management can be predicted to impact angler intentions and actions, as well as the different components of the resource system (Arostegui et al., 2021). Multiple pathways can be used to achieve the same goals, but it is important to understand the features of each pathway to identify which is most efficient, and to anticipate any additional outcomes that may occur and their desirability. Some aspects of these pathways can be evaluated by predicting how changes to angler characteristics can influence anglers' intentions and subsequent actions (Cooke et al., 2017), or how ecosystem modifications might result in changes to fish stocks or the characteristics of individual fish (Radinger et al., 2023). The model presented in Figure 1 is a simplification of the many complex relationships that exist in recreational fisheries as a SES. However, it provides a helpful structure for plotting out information needs and what aspects of a recreational fishery are likely to be influenced if that information is applied through management actions. The Swedish context of **Papers I-V** will be used to place this thesis in a country specific SES conceptual framework.

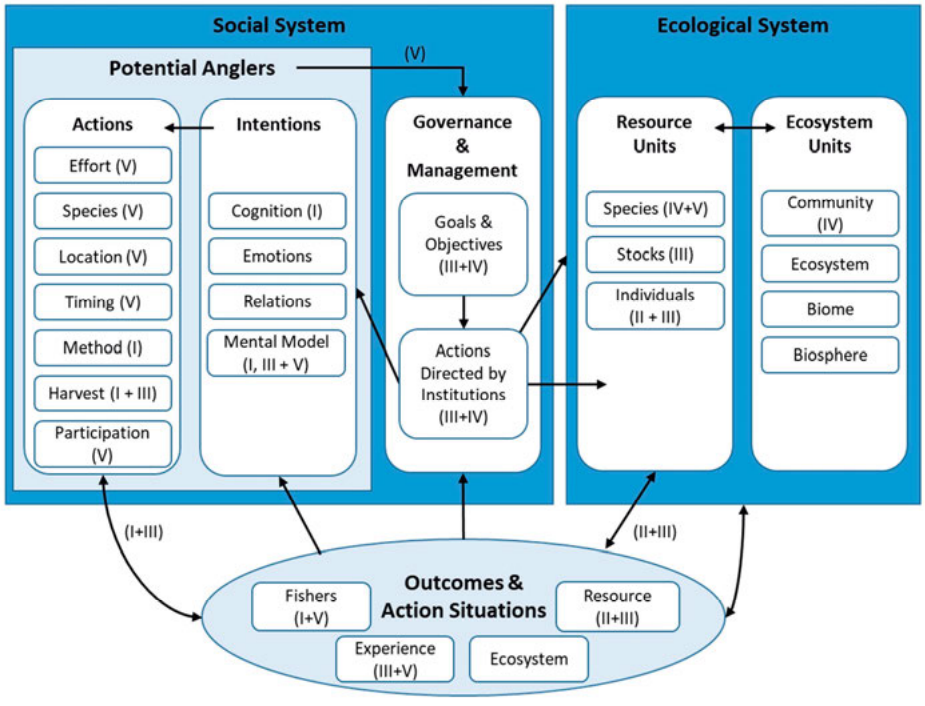

Figure 1 – Visualization of recreational fisheries understood as a coupled social-ecological system, highlighting the key relationships between the various components. Roman numerals I-V indicate components and relationships investigated in **Papers I-V** respectively. Adapted from Hunt *et al.,* 2013.

Social System

In the simplified model of recreational fisheries as a SES presented in Figure 1, the social side has two main parts. One is the structure around governance and management of the SES, which can have the role of interpreting the desires of resource users, the status of the ecological system, and steering management of the system (Kooiman et al., 2008). Ideally, then setting goals, objectives, and actions to help balance these sides and achieve desirable outcomes. The second is the resource users, which are grouped separately from governance and management, although they have important feedback links to governance and management. This section represents the complex network of institutions and pathways through which information shapes the intentions of potential anglers, followed by the ways in which those intentions are translated into actions that affect the rest of the SES.

Governance and management

The governance and management of Swedish recreational fisheries occurs under a mosaic of public and private structures, identified through the many systems, individuals, groups, and organizations responsible for steering management processes (Kooiman et al., 2008). Fishing in coastal waters and the five largest lakes is managed by the national and regional governments, and fisheries in these areas are the focus of **Papers I-III** and **V**. In these waters a licence is not needed for angling, but detailed regulations do govern what is permitted (HVMFS, 2023). A portion of fishing in inland waters falls under the jurisdiction of regional governments (e.g., waters in alpine areas above the limit for agricultural production), which set specific regulations and sell fishing licences. The majority of inland waters are managed as property rights by private organizations or individuals that set the specific regulations for the areas that they manage and have the option of selling fishing licences, these are the focus of **Paper IV**. All of these systems also fall under broader EU level goals and regulations, which add further layers to the existing challenges of defining and delineating SES boundaries (Carpenter et al. 2009). For the purposes of this thesis the simple division into public and private management is sufficient, as these labels are representative of the management situations that are explored.

The combination of fishery governance stakeholders described above creates both opportunities and challenges for the management of recreational fisheries across the country. The latitude afforded to private managers can allow them to rapidly adapt management to changing circumstances as they occur. At the same time the relatively small size of many of these units and a lack of coordination between them creates challenges for achieving watershed level management and possibilities for conflicting communication of regulations and best practices to anglers (**Paper IV**). The various publicly managed fisheries provide opportunities for institutions with resources for research and monitoring of fish stocks to set regulations over large and contiguous areas, and to set the tone for private fisheries management. However, the lack of licensing for the coastal and largest lake fisheries limits the tools available to manage access, generate revenue for conservation, monitor participation, and pathways to communicate important information (e.g., best practices for C&R or changes to regulations). The diversity of stakeholders also creates difficulties in fisheries monitoring, as data collection lacks depth and harmonization across the various private, public, and NGO groups that perform these activities. This has played a role when drawing material from disparate sources into this thesis, particularly in **Papers III** and **IV**.

Under all the governance structures used in Swedish recreational fisheries, the options for formal enforcement of regulations is limited by the scale of resources available, and the number and distribution of fishers across the landscape, which is a common challenge for recreational fisheries management

(Potts et al., 2019). Formal regulations provide a framework that guides behaviour, but both non-compliance and voluntary behaviour beyond the scope of regulations play large roles in the real-world actions of anglers (Näslund et al., 2010; Wszola et al., 2023). This is particularly important given angler preferences for regulations that have less direct impact on their behaviour and may have less control over mortality of fish (e.g., preferring size limits and recreational fishing only areas, disliking fishery closures and certain gear restrictions)(Arostegui et al., 2021). In these contexts, social norms, informal sanctions, and individuals' awareness of best practices can play an important role in limiting the negative impacts of recreational fishing and promote sustainable interactions with these resources (Cooke et al., 2013b; Danylchuk et al., 2018; Mackay et al., 2019). As C&R is an explicit part of many common regulations (i.e., size limits), as well as being a voluntary behaviour in many cases, it provides an interesting lens to explore how anglers choose to behave, and what effects that behaviour has on fisheries. **Paper IV** explores privately managed fisheries and the balance between formal regulations requiring C&R and the communication of information on best practices that would allow C&R regulations to function as well as possible. **Paper III** presents the short-term impacts of scenarios using formal and informal regulations to recreational fish harvest in an open access and publicly managed fishery.

Personal communication with several managers of recreational fisheries in Sweden has revealed and reinforced anecdotal evidence that many management goals are focused on the use of a relatively limited and traditional set of tools that are characterized by easily quantifiable thresholds and measurement units (e.g., bag and size limits). This is similar to limitations in the monitoring of Swedish outdoor recreation identified by Ankre et al. (2016). Although, there are many reasons why these traditional tools should remain in fishery regulations, it is also acknowledged that they do not encompass all of the nuances of the SES that contribute to balancing the desired social and ecological outcomes (Arlinghaus et al., 2013; Arostegui et al., 2021). In addition, managers often rely on anglers voluntarily adopting and following regulations in the absence of effective enforcement (Chapman et al., 2018; Cooke et al., 2013b), but apply limited attention to matching the diversity of angler groups with a diversity of communication strategies to motivate compliance (Nguyen et al., 2012; Ward et al., 2016).

Potential Anglers

As anglers can be even more diverse than the species they target, it is important to be able to identify the characteristics of individuals or different groups of recreational anglers based on who they are, what they think, and what they do (Hunt et al., 2021). These factors vary over time and place, and result in anglers having situation specific decision-making processes (Sutton, 2003). This information gives fisheries managers and other stakeholders the ability to better target policies and tools that recognize resource user groups

and specifically address beneficial or detrimental impacts that they may have. Particular characteristics of groups of recreational anglers can indicate current patterns of resource use, and what management goals and outcomes are likely to be desirable to these users (Pitman et al., 2018a; Pitman et al., 2018b). Similarly this information can help identify challenges and opportunities for conservation that might be addressed by focussing on fisher behaviour and perceptions (Skrzypczak and Karpiński, 2020). For example, consumptive orientation can be used to estimate harvest rates or predict changes in fishery participation in response to changes in regulation or the state of a fish stock (Murphy Jr. et al., 2019). Nature-based motivations can reveal values associated with conservation of undisturbed ecosystems and wild areas. Angler specialization and avidity can be useful predictors of investment in fishing activity, and likelihood of further financial investment in fishing or support for conservation or stewardship (Cowx et al., 2010; Tufts et al., 2015).

At the societal level many of the benefits of recreational fishing are the same as, or directly linked to, the goals of the individual people who are fishing. In a particular fishing experience, recreational fishers may prioritize the desire to have fish to take home, sharing an experience with friends or family, or the opportunity to relax in a peaceful natural setting, as presented in **Paper V**. These personal expectations can help to establish the goals of fishery management if they are complementary to the broader ecological and social context of the fishery (Murphy Jr. et al., 2019).. Alternatively, they can represent barriers to sustainability yet to be addressed and overcome, as demonstrated by the role of the nature experience as an important part of engagement in recreational fishing that is difficult to account for and seldom acknowledged in broader fishery management plans (Fowler et al., 2023).

It is essential that fisheries managers have an accurate picture of who is using a recreational fishery, their current behaviour, and how they are likely to respond to changes in the resource or the tools being used to manage it (Murphy Jr. et al., 2019; Ward et al., 2013). Being able to predict responses to management tools and conservation initiatives should make it easier to draft these plans in such a way that improves compliance with regulations, or the adoption of best practices (Cooke et al., 2013b; Hutt and Bettoli, 2007). With careful planning to identify target areas and issues, along with suitable groups of resource users, communication can be used to facilitate improvements to pro-environmental behaviour (Allison et al., 2023). Better understanding of who the resource users are and what they do should also be helpful in reducing and resolving conflicts over resource use, as demonstrated by the successful and sustained recovery of Atlantic salmon in the Northwest River of Newfoundland, Canada through a SES management approach that included the perspectives of local resource users (Cote et al., 2021).

Recreational anglers start each fishing activity with a set of intentions that have been shaped by their prior knowledge of the fishery, habits, motivations for fishing, perceptions and other beliefs, but also by existing governance

structures, such as existing regulations that influence when and where they can fish, and which fish they have the potential to retain (Boonstra and Hentati-Sundberg, 2016; Geoff et al., 2018). In turn, these intentions drive the actions that individuals undertake while fishing. In the context of C&R, the motivation for and execution of actions around selecting fish for harvest and how fish are interacted with if they are being released are of particular interest, and are the focus of **Papers I** and **III**. These factors can contribute to a feedback loop between the anglers' mental models of the fishery and the outcomes generated by their actions (Hunt et al., 2013). Here behaviours may change in response to experienced changes to the resource system, or interaction with other anglers that encourage the adoption of new social norms and behaviours, such as using best practices for C&R (Danylchuk et al., 2018; Kagervall et al., 2014; Nguyen et al., 2012; Stensland and Aas, 2014). This thesis limits itself to particular aspects of the social side of the SES that pertain to anglers' harvest decisions and use of C&R, and how data on angler characteristics and diversity is collected through surveys, even though there are many other factors that play important roles in this side of the SES (e.g., social motivations, place attachment, and social norms).

Where and when people choose to fish can determine the level of pressure on a fish stock or habitat, or potential areas of economic opportunity. Predicting the amount of harvest that is likely to occur given the number and behaviour of the fishers using a resource is important for determining what level of restrictions to access should be set (Carlin et al., 2012; Cooke and Cowx, 2006), as explored in **Paper III**. Fisher characterization can also be useful for informing decisions about where to make investments in stewardship, habitat restoration, or in facilities enhancement that would improve the quality of the user's experience and potentially increase regional economic returns from fishing activity (Curtis and Breen, 2017; Schroeder et al., 2018).

Data on angler characteristics are usually collected through surveys, which are particularly useful for assessing SESs because of their ability to capture quantifiable information about both the biological and the human dimensions of recreational fisheries (Nieman et al., 2021). There are several different methods that are commonly used to recruit respondents to these surveys (Pollock et al., 1994), which can be used to target particular respondents that have knowledge and perspectives that are of interest to management. However, this can also introduce biases such as sampling bias (i.e. some anglers are more likely to be sampled than others; e.g. Griffiths et al. (2013)) and non-response bias (i.e. some anglers are more likely to respond than others; e.g. van der Hammen et al. (2016)), and the so-called "avidity bias" (Thomson, 1991), explored in **Paper V**. Consequences of these biases are that samples may not provide perfect representations of what is going on in a fishery, which could result in certain issues being overlooked or poor management decisions

being made, ultimately undermining a fishery's actual needs. **Paper V** explores some of these biases and the angler characteristics that can define or contribute to them when collecting data through surveys.

Ecological System

The entire activity of recreational fishing is dependent on the existence of something to fish for and places for the activity to occur. This applies to a wide range of situations, from searching for wild fish in near pristine wilderness and pursuing pelagic species in the vastness of the ocean, to stocking hatchery fish in a small manmade pond. Each of these examples rely on a range of biotic and abiotic factors that allow stocks and communities of fish to reproduce, grow, and remain healthy. The relationships between resource units (e.g., individual fish, species, or fish stocks) and ecosystem units (e.g., community, ecosystem, biome, or biosphere) can be very complex, with food webs and ecosystems containing a multitude of feedback loops and interdependencies that maintain their status. As such, the components and actions of the social side of the SES must all be considered as occurring within the limits of the ecological system.

Although entire fields of study are devoted to understanding the inner relationships and the limits of the ecological system, this thesis limits its scope to those components that are directly interacting with the social side of the SES (i.e., individual fish that are being caught and released, harvest and fish stocks, and differences in management among species). Human actions can degrade both resource and ecosystem units, but it is also possible for fishing activity to help maintain or even enhance these units (e.g., the targeted removal of invasive species (Heim et al., 2020), and selective harvest to enhance stock characteristics (Hessenauer et al., 2018; Sass and Shaw, 2020)). Fisheries management uses thresholds for various resource and ecosystem units to trigger interventions intended to maintain stability in the SES (e.g., adapting size and bag limits to reduce harvest pressure (Arostegui et al., 2021), captive breeding and fish hatcheries as temporary supplements to threatened fish stocks (McMillan et al., 2023), and water temperature based fishery closures (Van Leeuwen et al., 2023). Yet the responses of different systems, species, or even different individuals of the same species can vary greatly, which is one reason why fishery and ecosystem specific research are important for improving the understanding of how whole systems will respond to pressures from environmental changes, angler behaviours, or management interventions (Cooke and Suski, 2005; Cowx and Gerdeaux, 2004).

Resource units

Resource units, such as individual fish, species, or fish stocks, are the direct targets of recreational fishing activity. They are also at the heart of many man-

agement activities, as both formal and informal regulations are often simplified to focus on resource units. As an example, management can steer harvest regulation at the species level by targeting invasive species for removal, or vulnerable species for protection (Heim et al., 2020); at the stock level by aiming to achieve higher growth rates by reducing competition, or protecting larger size classes of fish (Hessenauer et al., 2018; Matsumura et al., 2011); and at the individual fish level by encouraging selective harvest of males while releasing spawning females. What is happening at these three levels of resource units also plays a large role for informing anglers' perceptions of the system as a whole, which can translate into shifts to their intentions and actions (Arlinghaus et al., 2017). Even without changing anglers perceptions, regulations that focus on individual species can have spill-over effects such as the targeting and harvesting of other species (Sutton and Ditton, 2005). **Paper II** investigates resource units as individual fish in their response to C&R, while **Paper III** expands to the stock level in the exploration of catches, harvest rates, and reproduction. **Papers IV** and **V** cover slightly larger units within the ecological side of the SES to investigate the distribution of management attention and fishing pressure across fish species and communities.

For individual fish, being caught by a recreational angler can be the factor that determines whether that fish lives or dies. There are many ways in which the future health and well-being of that fish can be impacted by this encounter (Arlinghaus et al., 2007). At one end of the spectrum there is the clear and final impact on the fish if it is killed and harvested as a result of being caught, and cumulatively this can have large negative affects on fish populations that are similar of those of commercial fisheries (Michailidis et al., 2020; Post et al., 2002). Short of deliberate mortality caused by the person who caught the fish, there are many factors relating to being caught that could result in delayed mortality or other non-lethal impacts to the fish's well-being or behaviour. Delayed mortality is death that occurs after the fish is released or escapes, and is a result of being caught (Cooke and Wilde, 2007). This can be a direct result of injuries incurred by being caught (some of which might include barotrauma, excessive bleeding, or injury to gills), exhaustion or other impairment making the fish more vulnerable to predators (Brownscombe et al., 2017; Brownscombe et al., 2013; Cooke et al., 2013a). Fish can also suffer sublethal effects that influence their ability or willingness to feed, reproductive success, or vulnerability to other changes in their environment (Arlinghaus et al., 2007).

Which fish and how many are removed from a population can impact the stock's ability to sustain itself, or drive other changes such as individuals reaching sexual maturity at a different size or change interactions between this and other species (Jensen et al., 2009). Selective harvesting can be used as a tool to encourage the growth of more and larger individuals of desirable species (Ayllón et al., 2018; Gwinn et al., 2015; Hessenauer et al., 2018; Jennings et al., 2009). Selection for harvest or release can also lead to changes in the

behaviour of individual fish (Lovén Wallerius et al., 2019), and inherited behavioural traits at the population level (Vainikka et al., 2021). Different fish have different responses to the pressures of recreational fishing. Individual fish, or different species of fish may each have unique responses to being caught, patterns of harvest, or the simple presence of humans in their environment (Ashworth and Ormond, 2005; Bower et al., 2019; Crisp, 1989). These differences can lead to a wide range of potential outcomes in response to recreational fishing pressure and fisheries management tools.

Ecosystem units

Ecosystem units such as communities of fish, ecosystems, and broader biomes are considered less often as distinct parts of traditional fishing regulations (e.g., size, bag, and seasonal limits) and may be more challenging to account for in these institutions. However, stewardship through the conservation, restoration, or enhancement of habitats and ecosystems are important actions for sustaining recreational fisheries, which also have the potential to generate a host of other ecosystem services (Blicharska and Rönnbäck, 2018b; Shephard et al., 2022). Ecosystem units also represent important non-catch related aspects of recreational fishing, such as the role of the nature experience in motivations to fish and satisfaction from fishing, which are touched on in **Paper V**.

Many species that are targeted in recreational fisheries fulfill important roles in food webs and larger ecosystems. Recreationally desirable species of fish can be prey for charismatic megafauna (e.g., trout or salmon eaten by seals or orcas (Hansson et al., 2017)), or compete with them for prey (e.g., the role of menhaden (*Brevoortia tyrannus*) in ecosystems on the Atlantic coast of North America (Innes-Gold et al., 2021)), requiring a balance between the provisioning service of fish for human use and for the needs of other species (Suuronen and Lehtonen, 2012). They provide humans with a number of ecosystem services that go beyond generating a nutritious source of protein that is rich in polyunsaturated fatty acids (Butler et al., 2009; Holmlund and Hammar, 1999; Sidhu, 2003). An example being regulating services, such as species that maintain balance in food chains and thereby reduce the likelihood of harmful algal blooms (Eklöf et al., 2020; Söderqvist et al., 2005). Anadromous species, such as Pacific salmon, provide a unique function of transporting nutrients from marine ecosystems back to terrestrial ones (Hilborn et al., 2003b). Other species, (e.g., bull trout (*Salvelinus confluentus*), bigmouth buffalo (*Ictiobus cyprinellus*), and northern pike (*Esox lucius*)) can be important indicators of ecosystem health. The presence, absence, and health of these species can provide a measure of factors such as water quality, or a warning of negative changes (Arlinghaus et al., 2010; Armstrong et al., 2003).

Simply by being in natural areas, human beings can disrupt how ecosystems function. How we get there and what we do in the ecosystem create the potential for greater disruption, but also opportunities to mitigate the impacts

that we have on the world around us. Motorized travel to and from fishing sites by boat, car, or aircraft can have impacts on a global scale through resource consumption and emissions. At a local scale these forms of transportation can also disrupt animal behaviour, physically damage aquatic and terrestrial habitats, and risk spills of fuel or other harmful materials (McConchie and Toleman, 2003). Recreational fishers have the potential to transport refuse to remote areas where they go to fish. However, recreational fishers can also provide an avenue for waste cleanup from waterbodies and shorelines, or network for identifying areas where there are problems with waste (Lewin et al., 2020).

Recreational fishers can provide an avenue for the distribution of invasive species and diseases, and in some cases a means to control them. There are many examples of the deliberate distribution of fish and other species outside their natural range with the intention of creating or enhancing fishing opportunities, though this is often at the expense of pre-existing natural balances (Dedual and Pickford, 2018; Heim et al., 2020). The release of unused bait can be a deliberate action that causes unintended negative impacts to food webs and ecosystems (Banha et al., 2023). Recreational fishers are also a cause of the unintentional transport of diseases (*Gyrodactylus salaris*), pests (zebra mussels), or other invasive species (types of algae) that have large negative impacts on fisheries and the other ecosystems services that society would like to derive from these natural systems (Escobar et al., 2018). However, recreational fishers can also provide a useful means of monitoring the spread of these undesirables by reporting sightings of them while out fishing (Venturelli et al., 2017). Targeted harvest and removal of invasive species, such as snakeheads (*Channidae spp.*), and various types of cyprinids (carp) in North America, can be tool for slowing the spread and impact that they have (Herborg et al., 2007).

Recreationally targeted fish stocks and the ecosystems that support them are also heavily influenced by many factors and human activities that are not directly related to the recreational fishing activity itself. Hydroelectric dams, drainage and irrigation projects for agriculture and forestry, and pollution all have the potential create risks to the sustainability of fish stocks and the recreational fisheries that use them, as well as to other fishery related ecosystem services (Laine et al., 2002). Participation in recreational fishing can lead to greater awareness of these threats, as well as increasing the values associated with of fish stock and habitats, and generating a greater incentives for conservation (Cooke et al., 2016). As a result, management initiatives to mitigate these potential threats, such as habitat enhancement or restoration, are often undertaken by recreational fishers to protect the resource that they wish to use (Asah and Blahna, 2012; Cowx and Gerdeaux, 2004; Landon et al., 2018; Shephard et al., 2022). Restoring wetlands, rejuvenating riparian habitats, and building artificial reefs are examples of activities undertaken by recreational fishers to improve the resource that they desire, but that also would provide

other benefits to the environment and valuable ecosystem services to the non-fishing members of society (Blicharska and Rönnbäck, 2018b; Polizzi et al., 2015). Maintaining healthy ecosystems that are comprised of many different habitat types and their substituent components is also necessary to meet some recreational anglers' preferences for catching wild fish (e.g. Arlinghaus and Mehner (2005)) of a single or diverse range of species (e.g. Murphy Jr. et al. (2019)), as wild populations of fish need access to suitable spawning habitat, as well as appropriate nursery areas, and food (Armstrong et al., 2003). This can require or lead to the conservation of habitats other than those where fishers would most like to catch the fish (Blicharska and Rönnbäck, 2018b). In the cases of migratory species, such as trout and salmon, this includes maintaining habitat connectivity, and healthy living and growing conditions over a much larger geographic area than a specific fishing pond or beat (Brackley, 2016; Degerman et al., 2012).

Outcomes and Action Situations

In this thesis, several papers focus on measuring and describing the outcomes of different recreational fishing activities. These include measures of anglers' satisfactions and experiences, as well as attempting to quantify the outcomes for resource units through angler impacts on individual fish and the role of harvest decisions on a fish stock as a whole. The papers also attempt to illuminate the feedbacks and interactions between these measured outcomes and the human dimensions and resource units that generated them.

In the broader map of the SES for recreational fisheries the separation of the outcomes and action situations from the other nodes helps to visualize how our measurement of changes to the other units often occurs at one or two steps removed from the unit itself. Measurements of fish stocks or their reproductive potential are often calculated based on small samples taken from the whole (Jennings et al., 2009), as is the case presented in **Papers II** and **III**. Ecosystem health is also measured using limited sets of indicators, which may be projected across larger areas. In addition, social outcomes are often extrapolated from surveys that are restricted by the number of respondents or the framing of questions that do not account for all of the factors involved, as is explored in detail in **Paper V**, and is a component of **Papers I** and **III**. These limitations can constrain and impair the decision-making processes used to govern and manage the SES, and illustrate the need to incorporate knowledge and understanding of as many different aspects of the SES as possible back into management actions.

Despite limitations to the precise measurement of outcomes and action situations in the recreational fisheries SES, there are a range of possible pathways for using this information to inform and improve angler intentions and actions, as well as the health of resource units, and to guide choices made in the governance and management of these systems. **Papers I** and **II** seek to

illuminate possible outcomes that deviate from anglers' desires and what is ideal for the status of the resource units. **Paper III** attempts to project possible outcome scenarios and give governance and management an edge on balancing social and ecological needs through future actions. **Paper IV** highlights gaps in management structures that could contribute to outcomes that fall short of their intended goals. While **Paper V** touches on some social and ecological outcomes, it focuses on improving of how outcomes and action situations are measured and interpreted.

3. Methodology

The first section of this chapter outlines the social and geographic scope covered by each of the papers in this thesis. The second section provides a brief description of each of the diverse methods of data collection used in this thesis, as well as presenting a short reflection on relative strengths and weaknesses of the methods used. The contributions of each data source to **Papers I-V** and to the specific objectives of the thesis are outlined in Figure 2.

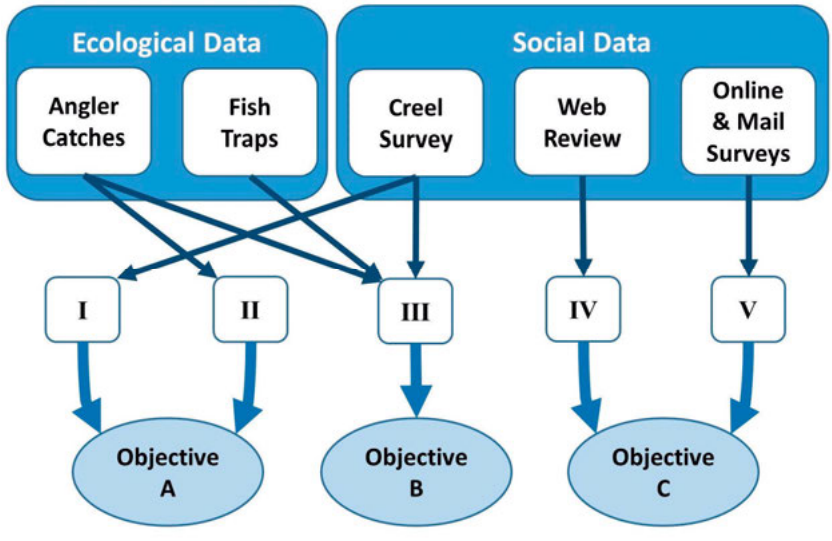

Figure 2 – The contributions of various ecological and social systems data to **Papers I-V**, and to the specific objectives of the thesis.

3.1 Scope of the Studies

This thesis consists of research conducted at three distinct socio-geographic scales that each represent unique and important aspects of the diversity of recreational fisheries management in Sweden. **Paper IV** looks at the management of private fishing waters across the country with data collected via a review of online sales platforms for fishing licenses. These are representative

of the majority of freshwater recreational fishing opportunities in Sweden, and include a wide range of fish species targeted by a diverse group of participants.

Paper V focuses on a publicly managed fishery with a more limited geographic scope. Here a publicly managed, open access, multi-species fishery in the Roslagen Archipelago around Stockholm is examined through surveys of different groups of anglers. The study investigates their actions, behaviours, motivations, and satisfaction from fishing activity.

Papers I, II, and **III** focus on the Gotland open access coastal fishery that is publicly managed. However, this fishery is focused upon a single species (i.e., sea run brown trout (*Salmo trutta*) referred to as sea trout), with relatively defined boundaries for management, and the anglers participating in this fishery are more specialized and avid than the general fishing public in Sweden. The sea trout fishery on the island of Gotland presents a distinct and useful case study for investigating the social-ecological system and the relationships that exist around the practice of C&R. The island is a popular and well-known destination for sea trout fishing which attracts many domestic and international tourists as well as local anglers (Blicharska and Rönnbäck, 2018a). The fishery is open access and has limited regulations, but past research has identified high rates of voluntary C&R (Blicharska and Rönnbäck, 2018a). Together these factors mean that the decisions of individual anglers, and how they perform C&R could have many impacts on this fish stock.

3.2 Data Collection and Analyses

This section outlines how data was collected from each of the five main sources for **Papers I-V**. It is divided into sub-sections focused on the ecological dimensions and social dimensions of this research. For each data source there is a brief paragraph outlining the details of the method, followed by a paragraph providing reflections on the merits of each method and considerations for their future use.

Ecological Dimensions

Stress Responses

Data on actual catches for **Papers II** and **III** were collected by angling for sea trout on the coast of Gotland during fishing seasons in 2019 and 2020. The fish were caught using conventional spin and fly angling gear common to this fishery. Angling-related factors (fight time, handling time, air exposure, hooking location, and difficulty of hook removal), environmental factors (air and water temperature), and fish-related factors (length, body condition, spawning status, and the presence of pre-existing injuries) were documented. Stress lev-

els were measured through the combination of five reflex action mortality predictors (RAMP, **Figure 3**), and testing blood glucose and lactate levels. Linear regression models determined the effects of the independent variables (i.e., the angling, environmental, and fish-related factors) on the three stress response variables.

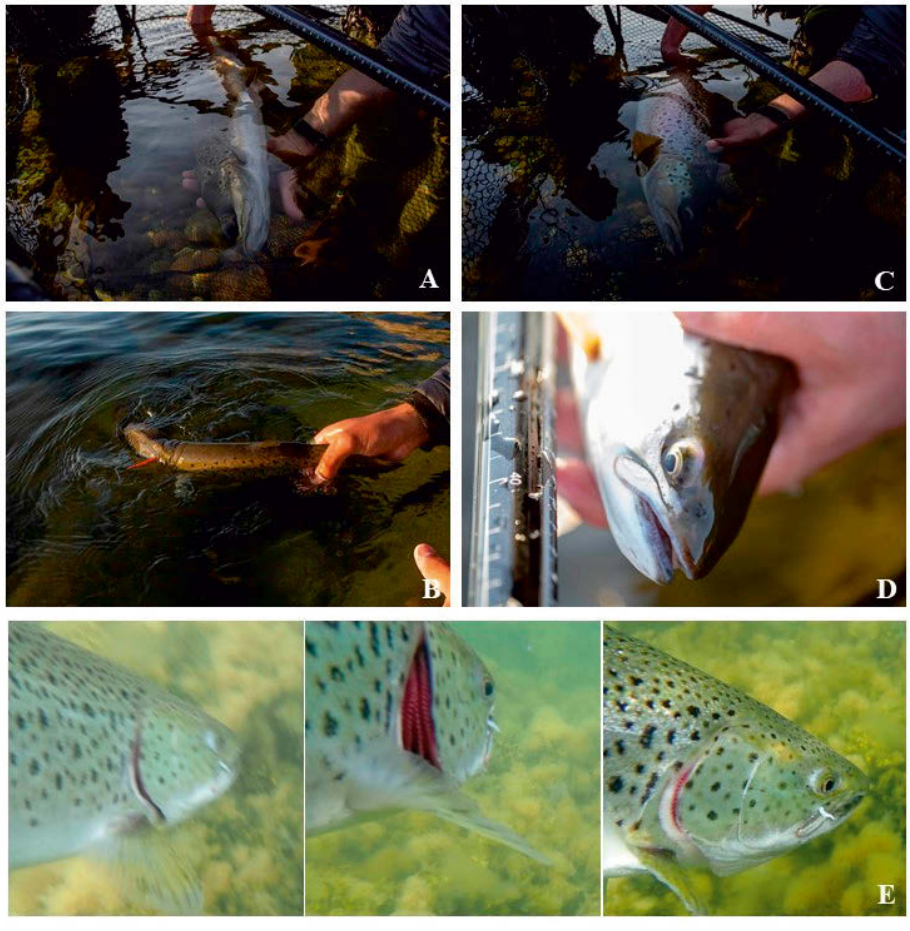

Figure 3 – Testing RAMP of angler sea trout using the vertical orientation reflex (A), swim burst response (B), body flex reflex (C), vestibulo-ocular reflex (D), and observation of operculum beats (E).

The validation of the RAMP thresholds for this specific fishery was a very important step when applying this methodology and ensuring that the suite of predictors measured were appropriate for this species and the conditions. Exploratory testing of RAMP for ide (*Leuciscus idus*), and garfish (*Belone belone*) illustrated that even under the same environmental conditions the physiology of different species can require the selection of a different set of reflexes to test. As well as, different baseline thresholds for determining the

presence or absence of each reflex. Any study using RAMP should confirm the fit of the tests to the target species and measure baselines for the speed of reflexes prior to any data collection.

The initial protocol for this experiment called for the clients of local fishing guides to catch the sea trout for testing. This was intended to allow the observation and quantification of common handling errors by a more diverse group of anglers. Clients were also to be tested on their ability to identify whether a sea trout was wild, had recently spawned, and if it was over the 50 cm minimum size. Unfortunately, due to the covid-19 pandemic it was not possible to follow this protocol for the majority of sampling. Instead, angling was performed by a group of individuals with a more uniform and high level of experience in the fishery. Although less detailed information could be gathered on how anglers generally handle sea trout before C&R, this change allowed for greater control of the angling event. Thus, individual angling events could be modified to better isolate individual drivers of stress responses during sampling, through actions such as extending air exposure or handling time for sea trout caught with very short fight times and no pre-existing injuries.

The choice of analyses for using this data in **Paper II** focused on identifying natural breaks in the data to highlight broad trends in stress responses that overlap with the items explored in the human dimensions of this fishery. Revisiting the data with an analysis that explores the independent variables at a finer resolution could define additional trends and thresholds in the responses of sea trout to C&R. One such avenue would be to use a MANOVA to look at the dependent variables in combination with each other and develop a more uniform measure of overall stress and its drivers.

Spawning Returns

The characteristics of the spawning population of Gotlandic sea trout explored in **Paper III** were extrapolated from the autumn returns of trout to three streams. There are 60 listed watersheds on Gotland, of which sea trout use many for spawning in at least their lower reaches. The regional office of the National Anglers Association (Sportfiskarna) and the Gotland Sportfishing Association monitor the returns of spawning sea trout in several of Gotland's streams. Sea trout were caught with fish traps (Figure 4) set at the mouths of the streams Själsöån 8 km north of Visby (2008, 2013, 2014, 2017-2019, 2021), Robbjänsån 30 km south of Visby (2017-2021), and Kopparviksbäcken in Visby (2020-2021) (Landergren, 2022; Sportfiskarna, 2021; Vallin, 2022). The traps were in place between the months of October and January, and checked daily for up-migrating sea trout. Fish entering the traps were counted, measured to the nearest cm (fork length, L_F), and sex was identified where possible before being released upstream of the trap. This data is publically available upon request from Sportfiskarna and the County Administrative Board of Gotland.

Figure 4 – Monitoring of fish trap for spawning sea trout set at the mouth of Själsöån north of Visby, Gotland during November 2018.

The monitoring of spawning returns on Gotland provided interesting insights into the issue of maintaining detailed, in depth, and harmonized data collection on the status of recreational fisheries in Sweden. These fish traps provide some of the only consistent data on the reproductive activity of sea trout in this stock. However, for several of the streams the collection of this data has only recently started as a component of habitat restoration efforts spearheaded by Sportfiskarna, and the available time series is relatively short. Data from Själsöån exists for a longer time series, but is not complete over the entire period, which is partially due to the reliance of monitoring on the voluntary actions of a local fishing club. Additional information collected at the fish traps including the weight of the fish, if the fish was wild, and the direction of travel in or out of the stream. Unfortunately, the collection of this information was not consistent across all documented fish, which limited opportunities for further comparison between spawning sea trout and angling catches. The on-going monitoring of spawning streams following habitat enhancement and restoration will provide an interesting opportunity for the future exploration of the carrying capacity of these streams and in the future could illuminate impacts from changes to size-based harvests in the Gotland sea trout fishery.

The returns data from multiple streams and multiple years were combined to smooth out annual variation that was predicted to be larger than what would be present in the data collected on actual catches and through the creel that

also informed **Paper III**. The heterogeneity of the three data sources encouraged the decision to limit much of the analysis to descriptive statistics to present simple comparisons between them. The projected scenarios give the relationships between these sources of data traction on the future status of this fishery; however, this can only provide a snapshot view of relative differences between approaches to management. To be accurate a more detailed long-term projection of the modelled scenarios would require more data than is currently available for this fishery.

Social Dimensions

Creel Survey

The data on angler perspectives for **Papers I** and **III** was collected through a roving intercept survey of sea trout anglers actively fishing on the coast of Gotland during the peak of the spring fishing season of 2018. The survey focused on characterization of the sea trout anglers and their catch/retention rates, the anglers' motivations for releasing or retaining legal sized sea trout, and anglers' rating of importance for a series of factors that could increase the likelihood of a C&R event being successful. The respondents were also asked to identify the circumstances in which they would photograph sea trout that they intended to release. They were tested on their knowledge of minimum length regulations and awareness of delayed mortality in released fish. Angler characteristics were assessed based on the categories of catch, skill, and social-based motivations for participating in the fishery, as well as general demographics.

The sampling protocol used in this type of intercept survey was intended to improve the quality of quantitative data collected, and validate the distribution of responses in a previous study gathered through snowball sampling of the fishery. By meeting with anglers that were actively fishing for sea trout it was hoped that a number of sampling biases could be reduced, such as recall bias or non-response biases related to willingness to devote time to completing a survey. Respondents were generally very enthusiastic about being included in the survey. The questions could be answered in under 15 minutes, although the desire of many respondents to communicate further resulted in some surveys taking up to an hour in cases where many additional stories or conversations were incorporated into the process. These extended interviews and conversations added a great deal of invaluable information on the perspectives held by different sea trout anglers and provided material for consideration that was outside the framing of the current survey. This information was particularly useful when planning the additional studies that are part of this thesis and for identifying future areas of research, which would have practical applications desired by anglers in this and other fisheries. However, this sampling

protocol was very time and labour intensive relative to the number of responses obtained. Future use of creel surveys in this fishery would benefit from a more detailed weighting of survey sites based on their popularity, accessibility, and current fishing conditions to ensure higher rates of intercepting anglers on the coast, such as the stratified random multistage design used by Gundelund *et al*. (2020).

One of the initial goals of using this data in **Paper III** was to identify angler characteristics or key groups that could be correlated with particular behaviours or C&R knowledge deficiencies. Clustering of responses did allow for the definition of some distinct angler groups, however the differences among these groups did not extend to correlations with the aspects of C&R being investigated. Exceptions to this situation were only present in cases where sample size limitations prevented the results from being interpreted as reliable representations of the subpopulation.

Online and Mail Surveys

The survey behind **Paper V** was aimed at two different target groups (populations) 1) the general public and 2) members of Sportfiskarna. For distribution to the general public the addresses of 2000 people aged 16-75 and registered in Uppsala or Stockholm County were purchased from the state's personal address register. Access to Sportfiskarna's membership register was free of charge, and at each mailing (survey period) 500 e-mail addresses for residents in Stockholm and Uppsala counties were randomly selected. Sample sizes were aimed to be similar to previous study conducted in the area (Soutukorva and Söderqvist, 2005). The general public were sent a letter with a background description and a short link with an associated QR code to a website where the survey could be completed (SurveyMonkey). Members of Sportfiskarna were emailed the same description, but with a digital link to the same website. The mailings did not include a personal login and were answered completely anonymously.

The survey was divided into three different periods during the year 2018, spring (March-May), summer (June-Aug) and autumn (Sep-Nov). Unlike the previous study by Soutukorva and Söderqvist (2005), this one excluded winter (Dec 2018-Feb 2019). The general public were only surveyed following the summer (June-Aug) period. In addition to the invitation to the survey, two reminders were sent approximately ten days apart. The questionnaire was answered completely anonymously, but in order to manage reminders to the general public, the respondents were offered to fill in their name and zip code at the end. This information was used solely to sort out the reminder mailings. For Sportfiskarna this was handled entirely digitally.

The two sampling protocols used in this study directly exposed strengths and weaknesses in the data collection method and in what comparisons were possible to make during analysis. The survey directed to the general public

was limited to the summer period as this was when it was anticipated the highest amount of fishing activity as well as highest response rate would occur. The higher financial cost, as well as the large investment of time, required in mailing out individual reminders limited this sample to a single event rather than collecting responses over multiple seasons. Having Sportfiskarna deliver surveys directly through their mailing list, as well as the reminders, allowed this sampling to occur more efficiently and for it to be repeated over multiple seasons. The winter season was omitted due to time constraints as well as the assumption that it would have a limited contribution to the data collected due to having substantial overlap with the fall and spring seasons, and lower levels of participation. These differences are a direct example the sampling biases that are explored further in this study. They also created limitations on how thoroughly different factors and angler characteristics could be investigated.

Using this case to explore biases in recreational fisheries' survey data at a general level encouraged analysis that focused on identifying broader thematic differences in **Paper V**. As the human and ecological components of each fishery SES are unique, the choice was made to avoid highlighting the precise directions and scales of relationships between the measured dependent variables and the independent factors that are driving differences and biases. These components are not always going to follow the precise patterns of this system, but should be considered at a general level as potential drivers of biases when sampling from other fisheries. Methods and tools for analysis were also chosen with the intention of reducing sensitivity to differing sample sizes and other factors that would have confounded the detailed exploration of specific trends in this fishery.

Web Review

Data collection for **Paper IV** was focused on the information being communicated to anglers from online sources similar to the review of government webpages by Pelletier *et al.* (2007) and the review of NGOs by Sims and Danylchuk (2017). A random sample of 331 was made from a list of organizations that sell fishing licences online for inland waters in Sweden. Information was recorded on the organizations' characteristics, type and location of water being managed, licence cost, and sales platform used. Institutional grammar was used to classify statements on rules and regulations put forward by each management organization as well as recommendations for performing C&R. A list of 12 best practices identified in the literature on C&R, largely based on reviews by Arlinghaus *et al*. (2007) and Brownscombe *et al.* (2017), was used to categorize these recommendations for C&R. The presence or absence of best practice information was explored and compared with the organization characteristics, the presence of regulations mandating the release of fish, and the species targeted by these regulations.

The collection of material from online sources does not represent a comprehensive review of the information provided to anglers on regulations, and

C&R best practices in Sweden. Many fishing organizations also communicate information on-site through signage or paper copies of regulations and other advice. However, anecdotal evidence suggests that this information is no more comprehensive than what is presented online, and often less up to date. Anglers may also receive information from fishing media, social media, or government and non-government organizations that wish to improve fisheries management even if they do not directly manage specific fishing waters. However, the trend towards online retail and the accessibility of online information means that in many cases this information presented at the online point of sale may represent the only direct contact and communication between anglers and fishery managers.

The overall lack of best practice information found in this data set limited the number of directions in which analysis in **Paper IV** could be taken. Initial plans included exploring the quality of best practices communication in the context of whether or not they are being presented in fisheries where they are particularly relevant (i.e., barotrauma for zander (*Sander lucioperca*)) or of general relevance (i.e., limiting air exposure). As a result, the exploration of this data was simplified to consider the presence of best practices information as a binary variable.

4. Summary of Research Findings

4.1 Fishery Specific Research

This section summarizes the key findings of **Papers I-III**, which make a focused and fishery specific exploration of angling for sea trout around Gotland, Sweden and the use of C&R as a management tool. Together they illustrate that it can be valuable to apply a SES perspective to a relatively focused topic and place-specific fishery. Such an approach allows the identification of patterns in human behaviour, gaps in knowledge, and impacts on individual fish and fish stocks that have the potential to influence the fishery as a whole. These fishery specific findings could provide information that is of interest to similar fisheries elsewhere, and starting points to explore and improve management in other contexts.

To Eat or Not to Eat

Paper I presents recreational sea trout anglers fishing on Gotland as a group that generally have high levels of experience and specialization, and a diverse range of social, skill, and catch-based motivations for participating in this fishery. Release rates are very high with only 16% of catches being retained. The strongest motivation for retaining legal sized sea trout is if the fish are deemed unlikely to survive. Among respondents with more favourable attitudes towards retaining some of their catches, the release of legal sized fish is most strongly motivated by the spawning status of the fish. Taking photos of sea trout that were to be released correlates with anglers favouring the release of most or all of their catches.

Perspectives on how C&R should be performed do not have strong correlations with angler characterization based on components including catch-based, social, or skill-based motivations to fish. Water temperature, using single, and barbless hooks scored as significantly less important than other components contributing to the success of a release. Higher confidence in one's ability to perform C&R well correlates with higher catch per unit effort, lower retention rates, and giving an overall higher rating of importance to components that contribute to the success of a release.

After the Spawn and on the Hook

The results of **Paper II** suggest that sea trout can be relatively resilient to C&R angling events under most normal conditions for this fishery if C&R is performed responsibly and according the best practice suggestions. This is supported by findings that suggest low rates of post-release mortality and generally limited stress responses to angling events. Measurements of stress levels in angled sea trout (RAMP, and blood glucose and lactate) show less impact from angling related factors (e.g., fight time, handling time, and air exposure), than from environmental factors (e.g., air and water temperature), and fish-related factors (e.g., length, body condition, spawning status, and pre-existing injuries). Higher than expected rates (~10%) of tagged sea trout being recaptured suggest relatively low rates of post release mortality. This is particularly notable as the recaptured sea trout included fish and angling events that would have generated higher than average stress levels, as well as all of the recaptured fish having undergone the impacts of extra handling, blood sampling, and tagging.

Figure 5 – Sea trout with pre-existing injuries (A-C), injury from large treble hook (D), spawning sea trout (E), male post-spawn sea trout with typical colouration, kyped jaw, and poor body condition (F)

However, the findings also indicate that more factors contribute to stress responses in sea trout during angling events with long fight times, high water temperatures, and where the trout have pre-existing injuries or show evidence of having recently spawned (Figure 5). Additionally, single hooks are demonstrated to be significantly better than treble hooks for reducing hooking injury and are easier to remove. To further reduce risks of delayed mortality or sublethal physiological disturbances to sea trout during C&R anglers should be encouraged to limit cumulative total air exposure to <10 s (including when unhooking, photographing the catch, or any other air exposure), reduce handling time, and avoid any actions that increase risk of additional injury (e.g., bringing the fish onto land).

Imagination, Reality, and Reproduction

Paper III investigates the relationships among angler expectations, the real size distribution and origin catches, as well as the characteristics of fish entering streams to spawn. Balancing these different dimensions of the fishery is essential for managers to maintain the sustainability of the sea trout stock, and the experiences anglers desire for sustenance, pleasure, and sense of place. The sea trout caught around the Swedish island of Gotland have a reputation for being relatively large and of wild origin, these factors are anticipated by anglers as part of their fishing experience, and attract them to the fishery. Both fishery managers and resource users have a vested interest in maintaining these characteristics.

Angler expectations are accurate for size of catches, but underestimate the proportion of the fishery supported by wild stocks. Experienced anglers' visual estimates of catch lengths are relatively accurate, particularly when correctly classifying under-sized fish as below the 50 cm minimum size limit.

Female sea trout entering spawning streams and post spawn sea trout caught on the coast are significantly larger than spawning males and non-spawned angling catches. Furthermore, there is a higher level of harvest pressure on the larger size classes of sea trout based on the preferences of a segment of the angling population. As over 20% of angling catches are current spawners small changes to angler preferences or regulations could have large influences on reproductive potential in this fishery.

A 1.7 percent change in harvest preferences for the largest size classes of sea trout or a 0.64 percent change in overall harvest rates would both result in fish mortality changing significantly relative to current practices. In response to increased angling pressure, voluntary changes to sea trout harvest preferences could be used to maintain the desirable characteristics and sustainability of this fishery.

4.2 The Information Landscape

This section summarizes the key findings of **Papers IV** and **V**, which explore the broader information landscape of the Swedish recreational fishing SES. The study presented in **Paper IV** takes up the topic of C&R and the communication of best practices at the national scale. While **Paper V** investigates the collection of human dimensions data in recreational fisheries, and the biases generated when conducting surveys that may influence how that data can be used to inform fisheries management.

Informing Obligations

Paper IV explores local recreational fishery management organizations that sell fishing licenses in Sweden, and how they communicate best practices for C&R to anglers. The function of C&R as a component of sustainable recreational fishery management is dependent on angler adoption of scientifically informed best practices. This can be facilitated through communication of best practice information, yet uncertainties remain around the extent and quality of such communication. This study focuses on online license sales platforms, the type of water body where fishing occurs (e.g., streams, lakes, or both), what species can be targeted, and what best practices are highlighted.

This article identifies a general lack in quantity and quality of best practice information being provided by license sellers managing inland recreational fisheries in Sweden. Despite the majority of fisheries using management tools that require the release of at least some of the catches made (e.g., size limits, bag limits, and harvest bans), only a small fraction mentioned best practices with most only mentioning a single practice and with little consistency in which practices were given priority. The lack of information was particularly notable for northern pike (*Esox lucius*) and European perch (*Perca fluviatilis*) which are the most landed and the most released species nationally.

The findings of **Paper IV** contribute to discussions around how and why we view and treat species differently, when and how to improve communication of best practice information, as well as who should be responsible for leading such development when fisheries are privately managed.

Beyond Asking the Right Questions

Paper V investigates the results of a survey distributed between two different sample populations (i.e., members of the general public, and members of Sportfiskarna that fish in the Roslagen archipelago near Stockholm). The responses from these two populations are combined and regrouped around a range of variables that contribute to common biases in surveys of recreational fisheries (e.g., boat use and ownership, stock perceptions, place of residence, and gender). It also compares responses across different angling seasons. These potential

sources of bias and respondent characteristics are then compared using variables such as catch per unit effort and release rates, as well as psychological dimensions including motivations to fish and angler satisfaction.

The results of this study demonstrate some of the ways in which common sampling techniques and the grouping of survey responses in recreational fisheries can introduce significant sampling, non-response, and avidity biases that influence the interpretation of gathered data. The avidity, boat use, and gender of anglers reveal significant differences in how each of these factors influence psychological dimensions of fishing, even though they are correlated with each other. Seasonality and place of residence appear to have little impact on biases in the survey responses regarding psychological dimensions of fishing, but are important factors when considering target species in this fishery. Measures of satisfaction from angling appear to be more universal than catch-related measures, general and fishery-specific motivations for fishing.

These findings highlight many factors that must be taken into consideration when planning data collection to address particular fisheries management questions. Factors that relate to strong selection biases can skew responses away from accurately representing the perspectives of resource users. Similarly, biases linked to management or catch-related factors could lead to miscalculation of the pressures on fish stocks or other ecological units, depending on how data is collected. However, these findings also illustrate opportunities for focusing data collection on psychological dimensions and physical management issues that are of interest to fisheries managers, by strategically targeting or avoiding factors that demonstrate selection bias influences. They can also help when preparing tailor-made strategies to communicate with anglers that have diverse preferences and behaviours, which can in turn facilitate better compliance with the regulations and improve the adoption of best practices when angling.

5. Discussion

This chapter begins with a brief discussion that highlights connections among the key findings of **Papers I-V**, and linking the management issues presented in **Papers I-III** to the information landscape context of **Papers IV** and **V**. The second section identifies several avenues for future research to build upon the results of this thesis and improve understanding of the components and relationships that make up the SES of recreational fisheries.

5.1 Connecting Key Findings

The pairing of **Papers I** and **II** emphasizes the strength of combining natural and social science methods to identify and better understand the challenges of recreational fisheries management. Independently these papers are useful in painting more detailed pictures of the human and biological components of C&R in the Gotland sea trout fishery, respectively. However, it is when these results are compared that the key knowledge and behaviour gaps for C&R best practices in this fishery can be identified. In particular, increased sustainability of the fishery could be pursued through improving angler knowledge and understanding about the roles of hook type, water temperature, and the sensitivity of post-spawn fish in the success of C&R (Delle Palme et al., 2016). These messages address the specific needs of this fishery and are not necessarily highlighted when communicating universally relevant best practices for C&R, such as minimizing air exposure, eliminating contact with dry surfaces, and minimizing handling time (Brownscombe et al., 2017).

Incorporating the findings of **Paper III** into managers' understanding of this recreational fishery further highlights the importance of knowledge and behaviour gaps at the stock level. If relatively small changes to voluntary harvest preferences can represent significant changes to mortality for size classes of large spawning sea trout, then it could be assumed that even small changes to post-release mortality during C&R are also important at the population level. This is given further relevance by the responses that particularly large fish generate in some anglers. Even when they will be released, large fish may be subject to additional handling and air exposure while anglers attempt to prolong their interaction with the fish, and to capture memories through photographs that can become lasting totems for the experience (Child and

Darimont, 2015; Joubert et al., 2020). This is again compounded with respect to post-spawn sea trout, which are more likely to be longer than average catches, have more striking colouration, and in the case of males visually distinctive kypes. These features could all contribute to situations of increased handling prior to release, while these fish are vulnerable to increased stress and have particular value to the future of the stock if they can recover and reproduce again (Losee et al., 2023).

Comparing the information on best practices for C&R mentioned by management organizations in Table 4 of **Paper IV** we can see correlation with the knowledge or awareness indicated by sea trout anglers displayed in Figure 3 of **Paper I**. Limiting handling time, air exposure, and using wet hands while handling fish are mentioned more often by management organizations and were scored most highly when considering the release of sea trout. The use of de-hooking tools, and consideration of water temperature are both mentioned less by license sellers and appear to be given less importance by sea trout anglers. These correlations suggest a connection between the information landscape and the behaviour of anglers in Sweden, and that creating more attention on particular best practices could lead to anglers adopting them more frequently (Ban et al., 2019; Delle Palme et al., 2016). However, in contrast to this, hook characteristics are mentioned more often by license sellers, but were given significantly lower scores by sea trout anglers. This serves as a reminder that although having more information gives stakeholders clearer targets to aim at, it is not the entire solution to management challenges and does not guarantee behaviour change (Dedual et al., 2013).

Taking these issues and projecting them onto the national scale of **Paper IV** suggests that they could be even more pronounced for the many species and fisheries that are identified as being even more data and communication deficient with respect to C&R best practices than the brown trout studied in **Papers I-III**. As examples, this could be particularly problematic if low representation of best practice statements for pike, and zander (*Sander lucioperca*) is correlated with gaps in angler awareness and behaviour when releasing these species. For pike this is an issue considering the importance of large individuals in stocks of this species (Arlinghaus et al., 2010), and the long-term population decline of these size classes in Swedish stocks (Bergström et al., 2022). While *Sander spp.* are particularly vulnerable to effects of barotrauma during C&R events (Eberts et al., 2018). Gaps in angler behaviour and the attention of fishery managers may be even more pronounced for the many "other" species of fish that are often unrecognized in regulations, and ignored or undervalued as bycatch by anglers (Rypel et al., 2021).

While **Papers I-III** indicate opportunities for improving communication and management at the fishery specific level, incorporating the results of **Papers IV** and **V** show that addressing knowledge and behaviour gaps are a valid priority at the national level in Sweden. Correlations between the knowledge

of avid anglers about C&R best practices in **Paper I** and the general information presented (or the lack thereof) in **Paper IV** suggests connections between the knowledge and behaviour of experienced and specialized anglers, and what is communicated to the general public. The diversity of anglers and factors influence their angling activity, illustrated in **Paper V**, contribute to the understanding that communication with fisheries stakeholders requires the use of multiple strategies and communication platforms to be effective. This diversity in communication is needed to ensure that relevant information actually reaches its intended audiences, and engages anglers in a meaningful manner that improves compliance with regulations and behaviour shifts to adopt best practices while fishing (Murphy Jr. et al., 2019; Nguyen et al., 2012). Also, greater understanding of angler diversity can guide decision makers design of angling regulations and management adjusted to the preferences and needs of different angler groups (Cote et al., 2021; Hunt et al., 2013).

5.2 Future Directions

The collage of different management practices and varying qualities of communication from license sellers identified in **Paper IV** is a situation that warrants further research. On the topic of management geography in Sweden there is much to be explored regarding the collaboration and coordination of regulations and management goals among private license sellers at the watershed level. This is particularly important given the findings that rules and communication of best practices are not consistent across fisheries or among species being managed, particularly if these fish move between management units within a watershed (Bower et al., 2015; Holder et al., 2020). Identifying the foundations and pathways that have contributed to particular organizations or fisheries adopting more proactive rather than reactive management could be used to create a road map for other organizations to follow towards improving their stewardship of fishery resources.

Exploring the communication of C&R best practices in Sweden's privately managed fisheries highlights opportunities to improve our understanding of how anglers are using this fishing practice and management tool. The identification of particular deficiencies in the quality and quantity of what is being communicated can guide future research (Holder et al., 2020). As the knowledge and behaviour of anglers as well as the particular sensitivities of different species varies from fishery to fishery, research is needed to identify which aspects of C&R are the most important to improve in different contexts (Cooke and Suski, 2005). The findings from **Paper IV** emphasize a lack of attention being given to C&R best practices in several fisheries, and that particularly those targeting pike, perch, zander, and so called "rough" fish deserve increased attention on both the practices commonly employed by anglers, as well as the responses of these species to C&R. These findings also contribute

to ongoing discussions around how and why we view and treat species differently (Rypel et al., 2021), who should be responsible for leading such development when fisheries are privately managed, as well as when and how to improve communication of best practice information (Cooke et al., 2017).

There is a need for deeper understanding of which communication pathways are the most efficient at reaching different angler groups to encourage the adoption and sustained use of best practices and responsible behaviour. The identification of knowledge and behaviour gaps in the practice of C&R among sea trout anglers is a useful first step towards identifying which messages to focus on in the Gotland fishery. However, the efficient bridging of these gaps would benefit from a deeper understanding of what pathways (e.g., regulations, social media, traditional media, from industry, or peer to peer) are most effective for communicating with different individual anglers and angler groups. The findings of **Paper V** support the idea that messaging needs to be tailored to different groups of anglers as the factors that motivate them and drive their behaviours can vary greatly (e.g., the desire for better fishing, reducing personal impacts on the environment, avoiding punishment)(Hunt et al., 2013; Nguyen et al., 2012). It is worth noting that this does not just apply to the adoption of best practices for C&R. Effective communication is also needed to inform anglers about what and why fishing regulations and management tools that are in place, so they can better understand what is expected of them and outcomes that are expected for the fishery (Dedual et al., 2013; Fenichel et al., 2013). This also applies to the pathways for communication from anglers to management as they are very important sources of data and bottom up engagement through citizen science (Harris et al., 2021; Potts et al., 2021; Skov et al., 2022), and their perspectives are essential for shaping effective regulations (Cote et al., 2021).

Paper II provides improved resolution and novel information that can be used to improve how C&R is applied locally, and many of the findings align with results of research in other fisheries on the stress responses of salmonids during C&R (Gargan et al., 2015; Lennox et al., 2017; Meka and McCormick, 2005; Skov et al., 2022). Yet, the finding that sea trout which have recently spawned are more vulnerable during angling events highlights a topic that has largely been overlooked in previous literature where the focus has been on the impacts of pre-spawn angling on salmonids and other fishes (Havn et al., 2015; Lennox et al., 2015; Thorstad et al., 2007; Twardek et al., 2018). Also, indications that water temperature starts to have a role in stress responses at temperatures as low as 10°C provides nuance to discussions that usually focus on the upper temperature thresholds at which C&R can be successful (Havn et al., 2015; Van Leeuwen et al., 2020). These findings are important for highlighting potential gaps in knowledge about C&R best practices in other fisheries, and the need for additional research to identify and understand them.

Within the coastal sea trout fishery there is also a great deal more to learn about the movements and behaviour of these fish after they are released. Obtaining higher resolution data, such as through acoustic tagging and setting up a sensor array around Gotland, would allow for a better understanding of many aspects of the fishery (Brownscombe et al., 2019b; Cooke et al., 2022). Post-release behaviour and survival could be assessed in more detail to improve recommendations for C&R best practices. Seasonal movements and habitat use could be mapped to better time the closure of protected areas around spawning streams (Chen et al., 2023; Flink et al., 2023). In addition, the inclusion of Gotland into the broader array of sensors around the Baltic would allow greater understanding of connectivity between populations and across the broader seascape (Cooke et al., 2022; Strøm et al., 2021).

Improving the quantity and quality of data on the population status and reproductive potential of the Gotlandic sea trout population would also allow for better modelling of the stock's responses to different angler preferences and regulations. The findings of **Paper III** only provide a snapshot of single year impacts from harvests on different segments of the sea trout population, with a broad extrapolation to the possible impacts on recruitment and future stock characteristics. More detailed information on the growth rates, capacity of other spawning streams on the island, harvest by recreational net fishers, and other material could be used to model harvest scenarios that account for the compounding effects of multiple years of fishing activity (Matsumura et al., 2011; Wilson et al., 2019; Wszola et al., 2023). Angler perceptions data should also take into account the potential for shifting reference points due to fishing induced evolution (Heino et al., 2013).

This thesis consistently makes the case for pursuing more data and greater understanding of the connections among the different components of the recreational fisheries SES. Ideally this would help stakeholders to do things right the first time, rather than screwing up and trying to fix it afterward. This is important, but it should not let the dream of a perfect plan and understanding of the system get in the way of applying good plans and using what we already know. In some cases, there will be parties that use the connected nature of the SES to shift blame and responsibility to other stakeholders in the system, or delay action while waiting for more information. Individual anglers may not feel that they have much agency or impact on larger issues (e.g., climate change, competing commercial harvest, predation, invasive species) facing the fisheries that they are a part of. However, they do have direct control over some aspects, such as using best practices to perform C&R as well as possible and thus contribute to stocks with more and larger fish. Fisheries management should use the information that is available to the best of its ability, while remaining mindful of and watchful for actions impacting other parts of the SES. As well as being prepared to incorporate and act on new information as it becomes available.

6. Conclusions

The sustainable management of recreational fisheries is particularly challenging due to the great number and diversity of their components, the complexity of the relationships among them, and that our knowledge and understanding of these many factors remains relatively limited. Using a SES perspective to explore the management of Swedish recreational fisheries provides valuable insights into angler diversity and behaviour, the responses of individual fish and fish stocks to particular management tools, and some of the strengths and weaknesses that are present in communication to and from fishery managers and researchers. This information offers opportunities to improve the quality and function of several fishery management tools

The findings of this thesis increase understanding of the direct relationships between the social and ecological aspects of Swedish recreational fisheries. Applying the SES framework to investigate C&R in the Gotland sea trout fishery identified and illuminated key knowledge and behavioural gaps that impact the role and function of C&R as a management tool in a high value fishery with particularly avid and experienced anglers. The relative importance of these findings might have been overlooked if research attention was focused on only the human or ecological dimension of C&R within this SES. By identifying actions that improve the quality of C&R for sea trout, this information can help anglers to avoid the undesirable outcomes of releasing fish that are unlikely to survive or suffer other negative impacts to their behaviour and well-being.

It is demonstrated that small changes to anglers' voluntary harvest preferences could result in significant changes to overall mortality for sea trout in the Gotland fishery. This gives additional weight to the importance of improving C&R practices through the opportunities identified in this thesis, as incremental improvements to the survival and well-being of released fish could also lead to significant benefits at the stock level. Identifying different angler motivations for releasing or retaining their catches, and general motivations for fishing can be used to tailor communication and outreach to attract and influence distinct groups of anglers to adopt or continue particular behaviours.

This thesis verifies and explores some of the diversity that is present among different groups of fishery managers and anglers at the national level in Sweden. Across the country there is an information and management landscape that is inconsistent and incomplete about how management tools are applied

and communicated in inland fisheries. These are factors that could limit the potential of recreational fisheries to meet the desires of anglers and management, as well as their ability to remain sustainable and continue to function within their biological limits. This information disparity could also contribute to the diversity of recreational anglers' knowledge, attitudes, and behaviour. Recreational fishery managers in Sweden have a great opportunity to improve the status of the resources that they manage by addressing the limited quality and quantity of C&R best practice information that is communicated to anglers.

This thesis also illuminates opportunities to improve how we use surveys collect and interpret data on the human dimension of SES. Identifying factors that contribute to sampling, non-response, and avidity biases when collecting survey data can help to avoid these biases in future data collection, or use them to actively target resource users and information of interest. In addition to evaluating biases in the data that is used to inform management decisions, these findings are useful to consider when interpreting and addressing the fishery specific discoveries of this thesis, and when translating them to other fisheries.

In summary this thesis adopts a SES approach to investigate key components of recreational fisheries to 1) identify knowledge and behavioural gaps that impair the function of key fishery management tools, and 2) frame the information landscape that informs both the behaviour of resource users as well as the decision-making processes of resource managers. This thesis shows that a lack of angler knowledge reduces the effectiveness of management tools and identifies how the information landscape in recreational fisheries management needs to be improved. There are several opportunities to make fisheries more sustainable through improving the quality and co-ordination of information communicated by fishery managers, and through small changes to anglers' voluntary behaviour. Yet these opportunities are mirrored in the potential for negative impacts if knowledge and behavioural gaps are not bridged, and that having information is not the same as employing it effectively. Further work is needed to identify how best to communicate relevant information to diverse groups of anglers and achieve effective adoption of various best practices during fishing activities.

Svensk Sammanfattning

Fritidsfiske, ofta med spö och lina (så kallat sportfiske), är en viktig rekreationsaktivitet som attraherar hundratals miljoner människor till sjöar, älvar, kuster och hav globalt sett. Sportfiske definieras generellt som att fångsten inte bidrar till försäljning eller handel på marknader (d.v.s. kommersiellt fiske) eller utgör individens primära kostbehov (d.v.s. självförsörjningsfiske). Trots detta så representerar sportfiske en ekonomisk aktivitet till ett värde av hundratals miljarder dollar på årsbasis, och viktiga bidrag till att möta näringsbehoven hos individer och samhällen.

En hållbar förvaltning av sportfisket måste balansera ekologiska och sociala mål; välja från och implementera en rad olika regelverk och verktyg; verka under ofta komplexa förvaltningsstrukturer; och hantera mångfalden av resursanvändare gällande variationen i förväntningar, önskemål och faktiskt beteende. Denna komplexitet gör också att det finns många kunskaps- och forskningsluckor när det gäller den information som behövs för att möta behoven hos olika typer av sportfisken. I detta sammanhang ger social-ekologiska system (SES) ett användbart ramverk för förståelse och utformning av lämplig förvaltning.

Denna avhandling utforskar förvaltningen av svenskt sportfiske som SES i fem vetenskapliga artiklar. Tre studier av havsöringsfisket runt ön Gotland ger ett sammanhang för att undersöka de mänskliga dimensionerna av hur catch-and-release (C&R, d.v.s. att fångad fisk släpps tillbaka inom sportfisket) tillämpas, havsöringens biofysiologiska svar på C&R i detta fiske, och effekterna på fiskbeståndet i relation till sportfiskares förväntningar och fångster. Avslutande två studier belyser det nationella informationslandskapet för sportfiskeförvaltningen genom en undersökning av hur C&R 'best practice' kommuniceras till sportfiskare, och en analys av potentiella möjligheter och utmaningar som genereras vid insamling av data genom enkätundersökningar.

Förvaltning och beslutsfattande för att hantera sportfiske står inför många begränsningar när det gäller kvaliteten och kvantiteten av tillgängliga data, och en mängd forskningsfrågor återstår att besvara för att identifiera och ta itu med de komplexa utmaningar som dessa dynamiska SES står inför. Biologiska data är ofta begränsade till extrapoleringar från relativt små urval av populationer och samhällen som är spridda mellan förvaltningsenheter och påverkas ytterligare av en mängd andra faktorer som för närvarande är svåra att mäta

eller redovisa, såsom resiliens mot klimatförändringar, effekter av miljöåtgärder, eller helt enkelt bristen på baslinjedata och tillräcklig information för att göra bedömningar. Data för den mänskliga och sociala dimensionen saknas också vanligtvis för många typer av sportfisken och dessutom är denna data komplex gällande provtagning, representativitet och generaliserbarhet, vilket påverkar appliceringen av den data som samlats in genom olika typer av undersökningar.

Studier av C&R ger möjligheter att tillämpa olika forskningsmetoder för att bättre förstå några av utmaningarna för sportfiskeförvaltningen och några av lösningarna på dessa utmaningar. Obligatorisk C&R är en naturlig del av regelverket för sportfiske (t.ex. att fisk av en viss storlek måste släppas tillbaka), dessutom är frivillig C&R vanligt förekommande. C&R är en intressant utgångspunkt för att utforska hur sportfiskare väljer att bete sig, och de resulterande effekterna av detta beteende på både sportfisket i stort och resursen (fisken). Det finns sedan länge ett etablerat behov av att utveckla artspecifika riktlinjer för hur C&R ska utföras (så kallad 'best practice') för att ta hänsyn till mångfalden av fiskemetoder och dom biologiska förutsättningarna för olika fiskarter. Trots detta finns det fortfarande hundratals fiskarter som sportfiskare riktar in sig på och en mångfald av fiskesituationer där C&R 'best practice' inte är tillräckligt undersökt eller kommunicerad. Vidare finns det många möjligheter för forskningen att förbättra vår förståelse av de mänskliga dimensionerna av varför och hur människor utför C&R, eftersom mångfalden av biologiska svar på olika typer av fiskhantering återspeglar ett brett spektrum av mänskliga faktorer. Att tillämpa SES-ramverket inom denna avhandling för att undersöka C&R i ett specifikt högvärdigt fiske efter havsöring på Gotland med särskilt erfarna sportfiskare möjliggjorde identifiering och belysning av viktiga kunskaps- och beteendeluckor som påverkar C&R:s roll och funktion som ett förvaltningsverktyg. Den relativa betydelsen av dessa resultat hade troligen förbisetts om forskningfokuset endast placerats på den mänskliga eller ekologiska dimensionen av C&R inom detta SES. Genom att identifiera åtgärder som förbättrar kvaliteten på C&R för havsöring, kan denna information bidra till att minska negativa effekter som stress och skador på fisk.

Inom svenskt sportfiske finns flera olika typer av aktörer och resursanvändare med distinkta beteenden och mönster. Beteendet hos denna mångfald av sportfiskare påverkas av ett informations- och förvaltningslandskap som är inkonsekvent och ofullständigt gällande hur förvaltningsverktyg tillämpas och kommuniceras vid fiske i sötvatten över hela landet. Detta är faktorer som skulle kunna begränsa hållbarheten och den fulla potentialen hos sportfisket för att möta önskemålen från både resursanvändare och förvaltning. Denna avhandling belyser möjligheter att förbättra hur vi samlar in och tolkar data om den mänskliga dimensionen av SES. Identifieringen av faktorer som påverkar t.ex. urval, representativitet, generaliserbarhet och tillämpning är viktigt vid insamling av enkätdata, samt kan även användas för att fokusera

undersökningar mot specifika typer av resursanvändare eller riktade informationssatsningar. Denna kunskap är även central inom beslutsfattande och förvaltning av sportfiske för att förstå hur resultat kan tolkas och tillämpas samt även översättas mellan olika typer sportfisken.

Forskningsresultaten i denna avhandling ger insikter i de direkta sambanden mellan sociala och ekologiska aspekter av SES. Att reflektera över hur små förändringar i frivillig C&R kan resultera i betydande effekter i den totala fiskdödligheten betonar vikten av förbättrad C&R 'best practice'. Skillnaden mellan olika sportfiskares motiv för att släppa tillbaka eller behålla sina fångster samt allmänna motiv för att fiska kan användas för att skräddarsy kommunikation och uppsökande verksamhet för att påverka särskilda grupper av sportfiskare. Dessa resultat ger även möjligheter för fiskeriförvaltningen i Sverige att förbättra statusen för fiskresurserna genom att öka kvaliteten och kvantiteten av information om C&R 'best practice' som kommuniceras till sportfiskare.

Sammanfattningsvis har denna avhandling ett SES-ramverk för att undersöka centrala komponenter inom sportfisket för att 1) identifiera kunskaps- och beteendeluckor som försämrar effekten av regelverk och verktyg inom sportfiskeförvaltningen, och 2) rama in informationslandskapet gällande både resursanvändarnas beteende och resursförvaltarnas beslutsprocesser. Denna avhandling visar att kunskapsbrister hos sportfiskare minskar effektiviteten hos förvaltningsverktyg samt identifierar hur informationslandskapet inom sportfiskeförvaltningen behöver förbättras. Det finns flera möjligheter att göra sportfisket mer hållbart genom att förbättra kvaliteten och samordningen av information som kommuniceras av fiskeriförvaltare, och genom förändringar av sportfiskarnas frivilliga beteende. Samtidigt speglas dessa möjligheter i risken för negativa effekter om kunskaps- och beteendeluckor inte åtgärdas, och att ha information är inte detsamma som att använda den effektivt. Ytterligare forskning behövs för att identifiera hur man bäst kan kommunicera relevant information till olika grupper av sportfiskare och uppnå en effektiv applicering av olika 'best praxis' i samband med fiskeaktiviteter.

Förbättring av kvaliteten och kvantiteten på information som är tillgänglig inom sportfisket bör förbättra möjligheterna till en framgångsrik förvaltning till fördel för resursanvändare, resursenheter och miljön som helhet. Även om tillgång till mer information inte garanterar att alla intressenter inom sportfisket kommer att fatta rätt beslut för systemets hållbarhet, bör en bättre förståelse för det social-ekologiska systemets enskilda komponenter och deras relationer med varandra tydliggöra visioner om vad som eftersträvas, och samtidigt minska risken för felaktiga beslut.

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"The best fishermen I know try not to make the same mistakes over and over again; instead they strive to make new and interesting mistakes and to remember what they learned from them." ~ John Gierach

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