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Resilience Management for Conservation of Inland Recreational Fisheries

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Resilience thinking has generated much interest among scientific communities, yet most resilience concepts have not materialized into management applications. We believe that using resilience concepts to characterize systems and the social and ecological processes affecting them is a way to integrate resilience into better management decisions. This situation is exemplified by inland recreational fisheries, which represent complex socioecological systems that face unpredictable and unavoidable change. Making management decisions in the context of resilience is increasingly important given mounting environmental and anthropogenic perturbations to inland systems. Herein, we propose a framework that allows resilience concepts to be better incorporated into management by (i) recognizing how current constraints and management objectives focus on desired or undesired systems (specific fish and anglers), (ii) evaluating the state of a system in terms of how both social and ecological forces enforce or erode the desired or undesired system, (iii) identifying the resilience-stage cycles a system state may undergo, and (iv) determining the broad management strategies that may be viable given the system state and resilience stage. We use examples from inland recreational fisheries to illustrate different system state and resilience stages and synthesize several key results. Across all combinations of socioecological forces, five common types of viable management strategies emerge: (i) adopt a different management preference or focus, (ii) change stakeholder attitudes or behaviors via stakeholder outreach, (iii) engage in (sometimes extreme) biological intervention, (iv) engage in fishery intervention, and (v) adopt landscape-level management approaches focusing on achieving different systems in different waters. We then discuss the challenges and weaknesses of our approach, including specifically the cases in which there are multiple strong social forces (i.e., stakeholders holding competing objectives or values) and situations where waters are not readily divisible, such as rivers or great lakes, and in which spatial separation of competing objectives will be difficult. We end with our vision of how we believe these types of operationalized resilience approaches could improve or transform inland recreational fisheries management.

Keywords: adaptive cycles, anglers, complex systems, fisheries management, invasive species, natural resource conservation, resilience thinking, socioecological systems

INTRODUCTION

The idea of resilience has become widely attractive, and it is recommended that governance systems "manage for resilience" (Garmestani and Allen, 2014; Cosens and Gunderson, 2018; Burnetta et al., 2019). Yet, few descriptions of practical approaches to accomplish this have been made since the inception of the idea (Grafton et al., 2019). We suspect that in many cases, a myriad of definitions and perhaps misuse of resilience concepts has delayed the ability to operationalize resilience. Resilience is also an emergent property (Gunderson, 2000) that is difficult to quantitatively measure and consequently use for management decisions (O'Brien and Leichenko, 2000; Carpenter et al., 2001; Meyer, 2016; Pimm et al., 2019). Regardless, there have been efforts to operationalize resilience concepts across diverse disciplines, such as engineering (Francis and Bekera, 2014), land use and planning (Meerow et al., 2016), psychology (Block and Block, 1980; Tugade et al., 2004), social sciences (Adger, 2000), production systems (e.g., forestry, community gardening, and aquaculture; Okvat and Zautra, 2011; Rist and Moen, 2013; Rist et al., 2014), environmental education (Krasny and Tidball, 2009; Krasny and Roth, 2010), coastal development (Adger et al., 2005; Lloyd et al., 2013), and commercial (Marshall and Marshall, 2007; Coulthard, 2012) and recreational fisheries (Arlinghaus et al., 2013; Post, 2013).

Though the term resilience is used differently across disciplines, the concept related to natural resource management was made notable by Holling (1966) and the primary concepts were then summarized by Holling (1973). This and subsequent works detailing aspects of resilience (many from the Resilience Alliance) have generally defined resilience as the magnitude of a disturbance that will trigger a shift between alternative stable states of a system. This implies that systems characterized by greater or lesser resilience will be, respectively, less or more likely to shift resilience stages or even slip into alternative system states given a similar perturbation. The concept of resilience has also been supported by development of and adaptation to complementary processes, including adaptive management (Walters, 1986) and panarchy (Gunderson and Holling, 2002). These developments have likely propelled resilience concepts beyond scientific investigation to be at least superficially embraced by diverse institutions involved in the governance of natural resources, from forestry and fisheries to coastal human communities (Benson and Garmestani, 2011; Rosati et al., 2015). This is further evidenced by management agencies proclaiming their goals of "managing for resilience," as well as by requests for proposals prompting investigation of resilience concepts. Therefore, we believe that instead of "managing for resilience," we could view resilience as a "system characteristic" that can be managed. This would provide a more meaningful and valuable framework for operationalizing resilience concepts.

The purpose of applying resilience concepts is to produce adaptable management and governance structures more capable of sustaining key system services under a range of conditions (Holling and Meffe, 1996). That is, governance structures must assess how to sustain key system services in the face of unpredictable, yet inevitable, changes, and mounting perturbations (Holling and Meffe, 1996). Such changes and perturbations appear pervasive in the current context of a deeply and rapidly changing climate (Milly et al., 2008; Paukert et al., 2016), increasing globalization (Young et al., 2006), intensifying loss of species and biodiversity (Pimm and Raven, 2000), and accelerating technological advance and consumption [(United Nations Environment Programme (UNEP) and International Union for Conservation of Nature (IUCN), 2011)]. These types of changes are likely to disproportionately affect systems with lesser resilience. Management agencies have limited resources to sustain key system services, and a resilience framework can assist with allocating these finite resources more efficiently. Yet, a looming problem exists where integration of resilience to natural resource decision making is lagging or has never begun. Resilience concepts have not been fully integrated into routine decision-making structures by management agencies in the developed world (Holling and Meffe, 1996; Berkes, 2010). They are even less recognized in the developing world, and although resilience concepts may provide opportunities to enhance socioeconomic benefit from natural resources, practical methods of incorporating these concepts into resource management are required [National Academies of Sciences, Engineering, and Medicine (NAS), 2019].

We argue that the need for operationalized resilience is strong in many disciplines, but we turn our attention to one specifically—inland recreational fisheries in which humans catch fish for the primary purpose of leisure, though this may also overlap with other purposes, such as food or income (Brownscombe et al., 2019). Recreational fisheries are complex socioecological systems that are characterized by dynamic feedbacks between fish and angler populations (Arlinghaus et al., 2007, 2013, 2017; Daedlow et al., 2011; Pope et al., 2014). Resilience ought to be particularly pertinent to these fisheries, given the stresses inland systems face from climate change, water-use demands, urbanizing human populations, and invasive species (Lynch et al., 2017; Brownscombe et al., 2019). These socioecological disturbances have already been demonstrated to shift systems from one state to another (Arlinghaus et al., 2017). Temperature changes can alter growth and survival of fishes, which can benefit and limit certain fish populations (Sharma et al., 2007). Stocking of large piscivores can result in top-down effects, which can cascade to primary producers and either result in an increase or decrease in vegetation, depending on the number of trophic levels in the system (Eby et al., 2006). Invasive species can alter ecological communities and in turn reduce the quality of important recreational fisheries (Cucherousset and Olden, 2011). Some of these shifts were unexpected and have compromised many key system services. The multiple challenges facing recreational fisheries emphasize the importance of robust decisions in the face of an uncertain and unpredictable future.

The objective of this work is to provide a practical framework that describes how management agencies can "operationalize resilience"—that is, describe how resilience concepts can be used to frame selection of management strategies and decisions. We do not attempt to redefine core resilience concepts, but rather connect what has been established to existing management options for inland recreational fisheries. Our intention is to highlight resilience as a system characteristic to be considered when making management decisions. To accomplish this we (section Why Resilience Is Important for Management of Inland Recreational Fisheries) describe the importance and application of resilience concepts to the specific discipline, managing inland recreational fisheries for resilience, and (section Conceptual Model for Operationalizing Resilience Management of Inland Recreational Fisheries) present a conceptual model for operationalizing resilience management. We then (section Results) explore how the conceptual model may be used to identify viable management strategies. Following this we (section Discussion) discuss resilience-management linkages and address exceptional cases that may be problematic for our conceptual model. Finally, we (section Synthesis and Looking Forward) envision a future for recreational fisheries that adopts a resilience management framework. Though we use inland recreational fisheries as an example, the general approach we take could apply to other socioecological systems.

WHY RESILIENCE IS IMPORTANT FOR MANAGEMENT OF INLAND RECREATIONAL FISHERIES

Recreational fisheries are considered socioecological systems because their outcomes depend at least on dynamic feedbacks between two primary components—fish and anglers. These dynamic feedbacks are created by angler-fish interactions that occur at multiple spatial (e.g., local, regional) and temporal (e.g., daily, annual) scales (Ward et al., 2016; Kaemingk et al., 2018; Matsumura et al., 2019; Murphy et al., 2019). Recreational-angler behavior, such as how much to fish, where to fish, and what fish to target, depends in part on fish populations, because catch-related attributes, like expected catch rate, size, and harvest, influence angler utility (Hunt, 2005; Hunt et al., 2019). These fishing behaviors, in turn, affect fish populations, mostly through fishing-related mortality and potentially sub-lethal effects (Welcomme et al., 2010). As a result, understanding of both fish ecology and human social behavior is needed to anticipate how environmental changes or management actions will affect common key recreational fisheries management objectives, like sustaining fishing effort that provides economic activity and supports local jobs, increasing satisfaction that anglers receive from fishing, and sustaining healthy abundances of fishes (Hunt et al., 2013).

Globally, management strategies and approaches of inland fisheries are understandably diverse, but there are commonalties (Cowx et al., 2010; Welcomme et al., 2010). Common recreational fisheries management actions include biological interventions, like invasive species removal (Zipkin et al., 2009; Coggins and Yard, 2010), as well as augmentative actions, like stocking hatchery-reared fish or restoring fish habitat (Taylor et al., 2017). Fisheries intervention most commonly includes restrictive measures to reduce fishing mortality, such as limiting harvest size, bag, season, and sometimes the fishing gear used. There is also an emphasis on communication methods to promote desired angler behavior (Li et al., 2010; Nguyen et al., 2012). Management actions are often imposed regionally, but in some cases, actions and regulations are applied to specific waters (of which some management regions may have thousands). This has prompted increasing calls for strategically designed spatial management plans (Lester et al., 2003; Hansen et al., 2015), though such plans remain rare (Carpenter and Brock, 2004; van Poorten and Camp, 2019). Given that recreational fisheries are coupled human and natural systems, decisions on which actions to take and at what spatial and temporal scales must consider both social and ecological components, as well as legal and political constraints and mandates. In practice, decisions often hinge on fish population abundance and dynamics, as well as stakeholder (typically angler) perceptions and preferences (Ward et al., 2016).

We believe that resilience concepts are particularly useful for sustaining key system services provided by inland recreational fisheries. Practically, inland recreational fisheries management ought to consider resilience to adopt better decision making (Grafton et al., 2019). Resilience is a characteristic of any system and thus intrinsically important for inland recreational fisheries, even if it is not always well-recognized. Any given fishery will have some inherent "degree" of resilience. This resilience will likely determine the overall influence managers may exert on the system, and the logistical challenges with, and viable strategies for, realizing that influence. Systems that appear to be characterized by greater resilience should require less management intervention, whereas systems with lesser resilience will require more management intervention to sustain (Walker et al., 2002). Failure to recognize the resilience of systems is likely to have costs. Management decisions about strategies adopted and actions taken have opportunity costs (time, funds, and social capital) that in some cases might be better allocated. Given the suite of anticipated perturbations to inland recreational fisheries, it is likely that most decision makers will be facing conflicting challenges from multiple objectives. Making management decisions in a resilience context could better allocate scarce management resources, for example, by recognizing which types of management actions are best suited for attaining a desired state, or by recognizing when a desired state is practically unattainable.

CONCEPTUAL MODEL FOR OPERATIONALIZING RESILIENCE MANAGEMENT OF INLAND RECREATIONAL FISHERIES

Common resilience terms are defined (**Table 1**), but here we briefly explain the major aspects of resilience in the context of inland recreational fisheries. In recreational fisheries, resilience is a characteristic of a specific socioecological system (with soft spatial and temporal boundaries). For example, a system might be anglers targeting brown trout *Salmo trutta* and European grayling *Thymallus thymallus* Engerdal in Norway (Aas et al., 2000). Inherently, recreational fisheries systems will be affected by both social and ecological forces. Though in reality these forces are likely complex, here we consider them simply as the sum directional effects on the system, so for example, "positive social, negative ecological." The strength of these socioecological forces is expected to potentially interact in their influence on the system—but regardless will answer the question of "how would this system tend without management intervention?" Thus, the socioecological forces of the system should affect its overall resilience. Here, we consider the resilience of the system state can be described to exist in one of three stages of an adaptive cycle—structuring, structured, and restructuring, which together comprise the adaptive cycle through which a system can move. To managers, differences between a system in a stage of increasing resilience (building) and a system in a stage of decreasing resilience (collapsing) may be dramatic. The former could require substantially less intervention to sustain in the future, relative to the latter, which would require a reversal of ongoing processes.

The simplest conceptual model that we consider useful for characterizing a recreational fishery is illustrated (**Figures 1**, **2**) and outlined for practical application (**Box 1**). In short, the system is defined first by the management focus, then by the socioecological forces determining the system state, and finally by the resilience stage. In greater detail, the management focus will initially be defined by the governance filters, such as legislation or legal restraints, or political and government processes that are likely to constrain the focus to a reduced suite of fish and anglers. Examples of filters would be laws aimed at species protection (Endangered Species Act in the United States of America; Environment Protection and Biodiversity Conservation Act in Australia). Given these governance filters, the management focus is then narrowed to specific fish and anglers to be considered the target of management—the system. Finally, the management focus must be defined by preference. This preference defines if the management is focused on achieving a desired system or resisting an undesired system. For example, a system dominated by largemouth bass *Micropterus salmoides* might be desirable in the southeastern United States of America, but undesirable in Japan (Maezono and Miyashita, 2003) or subject to a mixed view in South Africa (see **Box 2**). While both fish and anglers are considered in the focus, the management preference may be focused more toward ecological (e.g., restoring native fish) or social (e.g., sustaining popular fisheries) ends, depending on the governance filters. We also note that management focus is used rather than management objective, recognizing that often the focus will incorporate more than one objective. Establishing these components of the management focus (filters, target fish and anglers, and management preference) can allow the system of interest to be defined.

The system can then be further characterized by the types of social and ecological forces acting on it, which we describe as the system state. Note that social and ecological forces may be synergistic and enforcing (both forces driving toward high resilience), antagonistic (one force driving high resilience, one low resilience), or synergistic and eroding (both driving low resilience). This creates four nodes (see **Figure 1**) for each of a desired (fore plane of **Figure 1**) and undesired (back plane of **Figure 1**) system. We describe a system on which management is focused and that has been characterized by socioecological forces as a "system state." A given system state may then be qualitatively described by the recognized resilience stages (structuring, structured, restructuring). These stages refer to the adaptive cycle, recognizing that stability breeds rigidity that will eventually tend toward reorganization. Finally, we describe specific system states and resilience stages in terms of the likely viable management strategies.

RESULTS

We believe that the utility of our conceptual approach lies in recognizing that certain combinations of management system preference, socioecological forces (state), and resilience stages will result in a limited number of viable management strategies. Thus, identifying these components of the resilience of these systems could support making decisions about management strategies and could forward management science through recognition of patterns in viable management strategies.

(i) Little intervention needed to achieve desired outcomes—A suite of state and stage combinations exist for which minimal management intervention is likely necessary to promote the preferred system. Desired system states with synergistic enforcing (+/+) social and ecological forces should sustain themselves with minimal intervention because the socioecological systems already tend toward the preferred management focus (**Table 2**, cells 1–2). Examples of such a structuring system state might have positive effects of recreational angling on conservation of management-preferred masheer *Tor* spp. in India (Pinder and Raghavan, 2013), or the emerging dominance of catch-and-release fishing for largemouth bass that occurred during the 1980s and 1990s in the United States of America, as angler behavior coupled with ecological traits resulted in desired states of high catch-rate largemouth bass fisheries (Myers et al., 2008). A reciprocal system state and resilience stage exists if an undesired system is restructuring under synergistic eroding forces [negative social and ecological, (–/–); **Table 3**, cell 12]. These forces ought

TABLE 1 | Terms and definitions.

Term	Definition
Adaptive cycle	Systems are not stationary, but rather oscillate between long periods of aggregation and transformation of resources and short periods of innovation.
Resilience	A measure of the amount of change needed to transform a system from one set of processes and structures to a different set (transformative features). A high-resilience state would require a substantial amount of energy to transform, whereas a low-resilience state would require a relatively small amount of energy to transform.
Panarchy	Interacting set of hierarchically structured scales that comprise socioecological systems. This framework connects adaptive cycles in a nested hierarchy.
Forces	Social and ecological processes that influence the specific system states and resilience stages. These processes may combine in additive or non-additive ways to enforce or erode resilience. For purposes of this paper and application to recreational fisheries, we characterize forces as synergistic (when forces align) and antagonistic (when forces oppose).
Management focus	The view through which sustainability of a system state and resilience stage is assessed and managed. Specifically, the management focus involves applying governance filters to select the specific system (fish and anglers of management interest) and then identify the desirability of the system state. The management focus will drive specific management objectives.
Management preference	The preferred state of the fishery system. This preference defines if the management is focused on achieving a desired system or resisting an undesired system.
Governance filters	Constraints external or not immediately inherent to the management focus and the coupled human-fish system. This might include legal stipulations (such as Endangered Species Act) or political economies and preferences—either of which may drive the management focus and eventually viable management strategies.
Target system	The group of anglers along with the species, suite of species, or size group of a species (e.g., walleye, native salmonids, or trophy largemouth bass) that are the subject of management objectives.
System state	Systems can exist under multiple sets of unique biotic and abiotic conditions. These alternative sets of conditions are non-transitory and therefore considered stable over relevant timescales. Due to social and ecological feedbacks, systems display resistance to shifts in sets of conditions and therefore tend to remain in one set of conditions until perturbations are large enough to cause a shift to another set of conditions.
Resilience stage	The characterization of a "general" system in terms of adaptive cycles (i.e., panarchy). Historically characterized by four stages; for purposes of this paper and application to recreational fisheries, we characterize with three stages (i.e., structuring, structured, and restructuring). Inherently, structuring and restructuring stages have lower resilience than structured stages.
Structuring	At a spatiotemporal scale relevant to management, the socioecological pattern or organization with respect to a focal species is developing. This is the growth or exploitation phase in the adaptive cycle.
Structured	At a spatiotemporal scale relevant to management, the socioecological pattern or organization with respect to a focal species established. This is the conservation phase in the adaptive cycle.
Restructuring	At a spatiotemporal scale relevant to management, the socioecological pattern or organization with respect to a focal species is collapsing and undergoing a reorganization. This is the release and reorganization phases in the adaptive cycle.

to act against the undesired state in a manner that hastens its restructuring, even absent management intervention. Cases where little action is needed for a specific management focus ought not to imply that management in general is unnecessary. Instead, it represents an opportunity for managers to shift resources toward other foci that may require more intervention and associated resources.

(ii) Little intervention needed because states and stages unlikely to occur and persist—A different suite of system states and resilience stages would likely require little intervention because they would be so rare and unlikely to persist. These consist of either desired or undesired states in synergistic eroding (–/–) stages and in structuring and structured stages (**Tables 2**, **3**, cells 10–11). Such cases are expected to be rare because it is not clear how the states could be structuring or structured given the coupled negative social and ecological forces. A special case may exist for cases where a desired or undesired state is in a restructuring stage despite synergistic building forces (+/+; **Tables 2**, **3**, cell 3). As with those described above, this situation seems unlikely to occur because the positive social and ecological forces seem unlikely to permit restructuring, unless there are strong forces beyond the recreational fishery socioecological system. For example, massive environmental or social changes from disasters, like war and disease epidemics, may physically restructure the environmental system and reprioritize the social system in ways that could relegate recreational fisheries management to irrelevance (e.g., World War II; Caddy, 2000).

(iii) Uncommon states and stages requiring action—Other system state and resilience stages are less common, but where they exist likely require intense management actions. These are cases where a desired state is restructuring under synergistic eroding (–/–) social and ecological forces (**Table 2**; 12), or where an undesired state under synergistic enforcing forces (+/+; **Table 3**, cells 1–2) is in a structuring or structured stage. The prominent examples of managing for a desired state despite eroding (–/–) social and ecological forces would exist when managing for a native species that is less popular and negatively affected by a more popular but invasive sportfish. For example, replacing the New Zealand non-native trout *Onchorhynchus* spp. and *Salmo* spp. fishery (currently managed by New Zealand Fish and Game) with the historical whitebait (*Galaxiidae*) fishery (currently managed by New Zealand Department of Conservation) would require a shift in social norms (i.e., convince anglers to prefer whitebait over trout) and

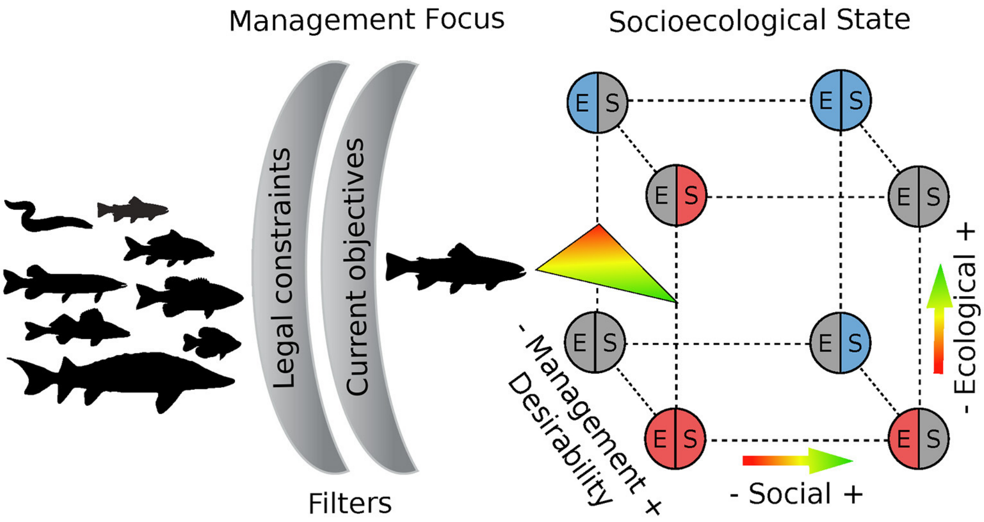


FIGURE 1 | Evaluating management resilience with respect to a focal species. Management resilience is evaluated with trout as the focal species filtered through legal constraint and current management objectives that help to determine the relevance of the species to management. The desirability of the species will fall along a spectrum (– to +) and can then be evaluated with respect to the spectrum of social (S) and ecological (E) forces (– to +). At the extremes, the nodes indicate the management action required to enhance resilience, with gray indicating no action, blue indicating management actions aimed at reducing the forcing component, and red indicating management actions aimed at enhancing the forcing component.

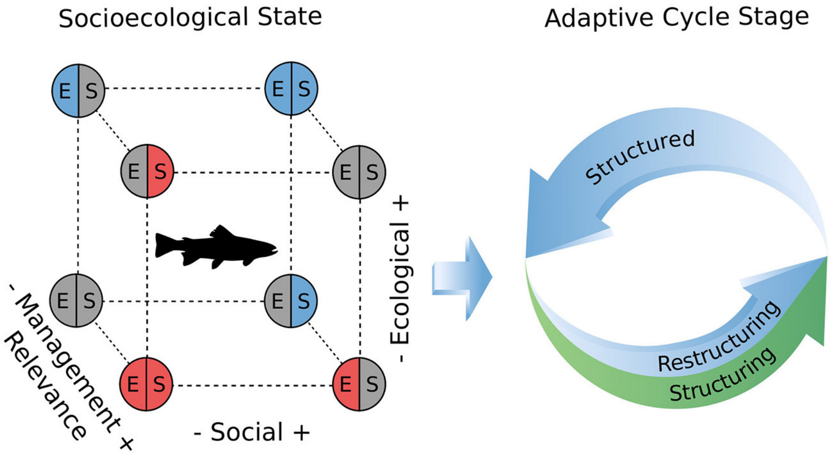


FIGURE 2 | Evaluating the system state with respect to a focal species once the node determining the nature of the action needed to maintain resilience in management is determined. The relevance of the species will fall along a spectrum (– to +) and can then be evaluated with respect to the spectrum of social (S) and ecological (E) forces (– to +). Systems are not stationary, and the malleability of the system state to management actions depends on the resilience stage (structuring, structured, restructuring) within the adaptive cycle. At the extremes, the nodes indicate the management action required to enhance resilience, with gray indicating no action, blue indicating management actions aimed at reducing the forcing component, and red indicating management actions aimed at enhancing the forcing component. The final options for management will depend on the system state.

involve intense biological intervention (i.e., trout eradication) to restore the native aquatic communities (Lintermans, 2000). One could argue that this is not possible (e.g., for the New Zealand Department of Conservation) and an unwise use of agency resources given the current socioecological resilience of the system. Such efforts, however, are not unprecedented, as intense trout removals occurred in the Colorado River to reduce mortality on the federally protected humpback chub *Gila cypha* (Coggins and Yard, 2010; **Box 3**). Where management agencies do elect to confront these challenges, there are two options: spatially explicit planning or changing the management focus (often by changing the management preference). Spatially explicit planning involves selecting certain waters in which to attempt to reverse the ecological forces, likely through intense intervention such as invasive species removals (Zipkin et al., 2009; Coggins and Yard, 2010).

BOX 1 | Steps for operationalizing.

We use the following steps to illustrate how the conceptual model could be used to operationalize management decisions. These steps can also be used to reveal missing and critical pieces of information that may require further research before proceeding. Some information was adopted from the Assessing Resilience in Socioecological Systems: Workbook for Practitioners (2010).

Step 1. ***Identify filters (legal constraints and current objectives)***

What are the legal constraints that should be considered?

What are the existing management objectives?

It is necessary to identify external and inherent legal constraints that may impede or promote certain management objectives and strategies. At the same time, it is imperative to identify the current management objectives that may be constrained or could direct the management focus.

Step 2. ***Identify management focus***.

What are the key socioecological forces of the system?

What are the spatial and temporal boundaries of the system?

What is the desirability of the system?

This step requires identification of key forces and associate interactions that are relevant to the management focus. These key components will have soft spatial and temporal boundaries that define the system. It is also important to recognize that the system will include cross-scale interactions that will be within and outside the established boundaries. Finally, the preferred state of the system should be clearly established given the management objectives.

Step 3. ***Define the current system state***.

What is the state of the system?

Is the state of the system desired or undesired?

A system can be described in terms of social and ecological forces that contribute to its current state. These social or ecological forces can create feedbacks that tend to support stability, unless social or ecological perturbations cause a shift into a new state. Therefore, it is important to characterize and understand how these social or ecological forces are influencing the current state. Defining the current system state then allows for discussion about whether it is desired or undesired, from both a social and ecological perspective.

Step 4. ***Evaluate the resilience stage of the system***.

Is the system in a structuring, structured, or restructuring stage?

It is important to recognize whether the system is in a structuring, structured, or restructuring stage in addition to defining the system state. Structured stages will inherently be more resilient than structuring and restructuring stages. Information concerning historical, current, and future states will be valuable for this step. Identifying the stage of the system is also essential for characterizing the system as being desired or undesired.

Step 5. ***Consider viable management options***.

What are viable management options given the current system state and resilience stage of the system?

A range of viable management options exist under different system states (**Tables 2**, **3**). Some system components may be enforcing resilience and others may be eroding resilience. Evaluating interactions of these forces allows for opportunity to effectively target social and ecological components and how they affect the system state. Careful consideration is necessary to explore these options and implement the most appropriate strategy, which in some cases may require very little action. However, hasty management actions could impede a favorable future system state without knowledge of the current system state and stage.

Alternatively, if management agencies consider the social and ecological forces insurmountable, agencies may elect to change their focus. Specifically, switching the management preference (from undesired to desired, and vice versa) converts these challenging scenarios to scenarios requiring little management action (described above). Changing the management focus will likely be difficult (especially depending on governance filters) but may prove more tenable in the long run. Embracing a new system state may allow for a greater breadth of viable management actions that accompany the "structuring stage" of an adaptive cycle. For example, many hydropower dam projects are planned for the Amazon, Congo, and Mekong river basins (Winemiller et al., 2016). Economic gain has been prioritized in these systems that will be accompanied with a loss in riverine species (Ziv et al., 2012; Anderson et al., 2018) and domination by lentic species. Cognizant of these looming changes, management agencies may elect to focus attention to these lentic species—such as promoting burgeoning fishing opportunities—rather than attempt to preserve the waning lotic fisheries.

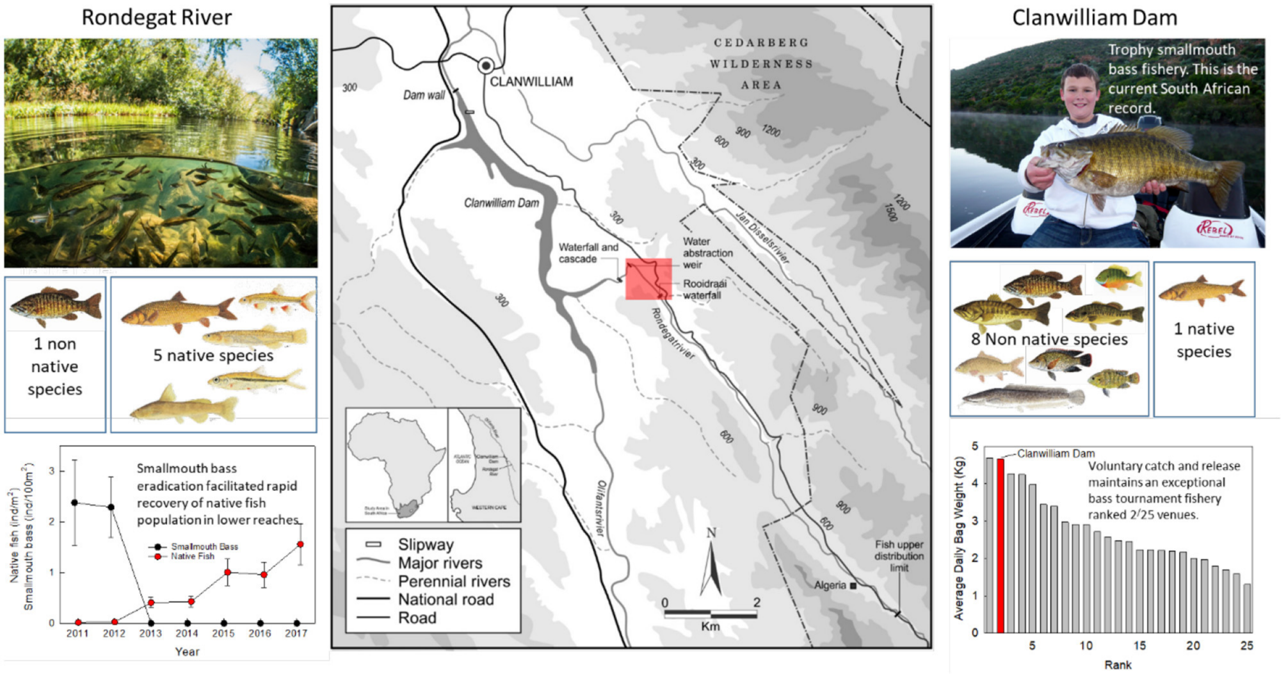
System states with opposing social and ecological forces (+/− or −/+) are likely to require the most intervention. For both desired and undesired states and across all stages (**Tables 2**, **3**, cells 4–9), there are essentially five management strategies that may be used singly or in combination.

(iv) Outreach and education—Endeavoring to alter stakeholder attitudes may be reasonable where social forces will oppose the management focus [i.e., −/+ on desired states (**Table 2**, cells 4–6), +/− on undesired states (**Table 3**, cells 7–9)]. Successfully changing what stakeholders want is likely to be challenging, but the potential benefit is altering the system forces so that the system state requires substantially less management intervention [e.g., shifting from −/+ to +/+ for a desired state (**Table 2**, cell 5 to cell 2)]. Outreach and education are sometimes the most feasible and may also be the least costly options, so in many cases, this will be the first management strategy to employ.

(v) Biological intervention—Biological interventions (e.g., stock enhancement, habitat restoration, invasive removal) are most appropriate with antagonistic forces where social forces align with management but are opposed by ecological forces

BOX 2 | Case study from Cape Fold Ecoregion, South Africa.

Many sport fishes, including several black bass (*Micropterus*) species have been stocked into South Africa's freshwater systems for the improvement of recreational angling opportunities (Ellender and Weyl, 2014). Smallmouth bass *Micropterus dolomieu* were introduced into South Africa in 1937 and rapidly established themselves in several freshwater systems (Khosa et al., 2019). Although this encouraged the development of recreational angling, which makes an important economic contribution to the South African Economy (Saayman et al., 2017), this species has resulted in the extirpation of endemic fishes (Van Der Walt et al., 2016). In the Cape Fold Ecoregion (CFE), a hotspot of regional fish diversity and endemism, predation by alien fishes is currently considered the primary threat to almost all of the endemic native fishes, and there is consensus among scientists and conservationists that this threat may jeopardize the long-term prospects for the endemic fauna (Ellender et al., 2017).



Similar to other parts of South Africa, conservation authorities in the CFE have been responsible for the management of freshwater fishes (Woodford et al., 2017). Thus, there has been a focus toward promoting conservation and very little emphasis on managing fisheries. In the case of smallmouth bass, management emphasizes the facilitation of fisheries in impoundments while trying to rehabilitate invaded headwater streams through directed eradication measures (Woodford et al., 2017). This is well-illustrated by their recent smallmouth bass eradication on the Rondegat River and their approach to the management of the Clanwilliam Dam in the Olifants River system (Weyl et al., 2014). From the perspective of the operationalization of resilience, the aim of the eradication project was to alter the structured, smallmouth bass-dominated state found in a reach of the Rondegat River. After the removal of smallmouth bass via the application of the piscicide rotenone, native fishes rapidly recolonized the rehabilitated section of river and within 2 years of the removal of smallmouth bass, the abundance and diversity was similar to that in the non-invaded reaches of the river (Weyl et al., 2014). In contrast to the conservation-based intervention in the Rondegat River, the management of the smallmouth bass-dominated fish fauna in Clanwilliam Dam has devolved to self-regulation by organized angler groups. Using the principle of voluntary release, the angler groups encouraged synergistic interaction of social and ecological forces and have maintained a stable state system for trophy smallmouth bass for decades. Indeed, Clanwilliam Dam ranked 2/25 with regard to catch weight and average fish size in an assessment of black bass tournaments held in southern Africa (Hargrove et al., 2015) and considered to be South Africa's premier smallmouth bass fishing destination with the national record of 3.52 kg captured in 2009. However, the recent illegal introduction of African sharptooth catfish *Clarias gariepinus* and an increase in the abundance of common carp *Cyprinus carpio* appear to have altered the ecological state of the fishery through bioturbation, and it appears that the stable "trophy smallmouth bass" state may be restructuring (Weyl pers. obs).

[i.e., +/− on desired systems (**Table 2**, cells 7–9), −/+ on undesired states (**Table 3**, cells 4–6)]. Examples might include removal of sea lamprey *Petromyzon marinus* in the Great Lakes of North America, where lamprey have been associated with negative effects on desired salmonid species (Coble et al., 1990). Managers must also consider that any biological intervention, but especially augmentative actions like stock enhancement, may well alter angler behavior and affect system outcomes (Camp et al., 2017).

A special case of biological intervention could occur if system states are deemed so precious and valuable that they demand (or legally require) all available resources to delay a likely inevitable collapse. These cases would likely be restricted to desired states with negative ecological forces in a restructuring stage (i.e., **Table 2** cell 9 and perhaps 12). Modern examples might include the exceptional measures taken to "rescue" (manually relocate) salmonids languishing in isolated pools of drying streams of western United States of America in the face of a climate

TABLE 2 | Examples and likely viable management strategies (in bold) for socioecological forces (rows) and resilience stages (columns) relevant for a desired management focus.

Forces	Structuring	Structured	Restructuring
+ Social/+ Ecological	1. +/+ on a building, desired system. Smallmouth bass and growing catch-and-release fishery in Pacific Northwest coastal rivers, USA. **Little action needed**.	2. +/+ on a stable, desired system. Catch-and-release oriented anglers and trophy largemouth bass in southern US ponds. **Little action needed**	3. +/+ on a collapsing, desired system. Rare, likely driven by forces beyond the recreational fishery socioecological system (SES) **Likely no viable mgmt. action**
– Social/+ Ecological	4. –/+ on a building, desired system. Coldwater/warmwater fisheries in Northern US lakes. **Outreach and education** **Fishery intervention** **Spatially explicit planning**	5. –/+ on a stable, desired system. Overfished recreational fisheries, such as Peacock bass in Brazil **Outreach and education** **Fishery intervention** **Spatially explicit planning**	6. –/+ on a collapsing, desired system. Potential recreational overfishing of Taimen in Mongolia. **Outreach and education** **Fishery intervention** **Spatially explicit planning**
+ Social/– Ecological	7. +/– on a building, desired system Naturalizing populations of introduced trout in Europe **Biological intervention** **Spatially explicit planning**	8. +/– on a stable, desired system Put-and-take stocked salmonid fisheries **Biological intervention** **Spatially explicit planning**	9. +/– on a collapsing desired system Rescuing native salmonids in western US streams affected by drought and climate change. **Extreme biological intervention** **Spatially explicit planning**
– Social/– Ecological	10. –/– on a building desired system Rare and unlikely to persist **N/A**	11. –/– on a stable desired system Rare and unlikely to persist **N/A**	12. –/– on a collapsing desired system Native cyprinids facing climate change and more popular, non-native trout in the Grand Canyon, USA. **Extreme biological intervention** **Spatially explicit planning** **Change mgmt. objectives**

1. In some rivers of Pacific Northwest, introduced non-native smallmouth bass Micropterus dolomieu have developed as a socioeconomically important recreational fishery that is desired by many anglers and to some extent by management agencies, though there may be negative effects on native salmonid populations (Carey et al., 2011). The popularity of smallmouth bass with anglers, coupled with their apparent ecological advantage in these systems, suggests that little management action is needed (as long as this new system is desired).

2. Catch-and-release ethic among trophy bass anglers produces a bass size structure that is likely associated with a high-quality fishing experience desired by anglers and management agencies alike in southern US lakes and ponds (Myers et al., 2008). Often little fisheries management intervention is needed.

3. No clear examples are apparent from primary literature, but a number of studies describe in passing the suspending of fisheries management actions associated with international conflict, such as World War II (Caddy, 2000).

4. Waters that were traditionally managed more for coldwater species (Esox spp., walleye Sander vitreus; Olson and Cunningham, 1989) are increasingly producing excellent warmwater fishing for species such as largemouth bass Micropterus salmoides (Sharma et al., 2007). Though management agencies may now prefer to manage for warmwater species, this is resisted by other anglers who prefer coldwater species. Here management might consider outreach and education to convert anglers to warmwater fisheries, regulations that encourage warmwater fishing, or managing only certain waters for warmwater.

5. Overfished inland recreational fisheries, such as the peacock bass (Cichla spp.) in Amazonia waters where they have been heavily exploited by (often tourist) anglers (Allan et al., 2005; Campos and Freitas, 2014). More restrictive harvest or even effort management may be needed if education (e.g., importance of returning large fish) fails to stem overharvest.

6. Growing fishing effort from tourist anglers targeting taimen Hucho tiamen in Mongolia, where the desired system is a sustained taimen population (Jensen et al., 2009; Golden et al., 2019). Though ecological conditions may still promote healthy taimen populations, it is likely that fisheries management would need to constrain harvest or even fishing effort if there is non-negligible catch and release mortality (Jensen et al., 2009).

7. Introduced but naturalizing populations of fish, such as rainbow trout throughout much of Europe constitute a system where social forces (popularity of rainbow trout) can lead to structuring states (trout fisheries) in systems that may not be ecologically well-suited (Stanković et al., 2015).

8. Put-and-take salmonid fisheries (in which catchable-sized fish are stocked repeatedly in waters in which they cannot spawn and sometimes cannot survive stresses of summer or winter) are popular worldwide and can produce stable fishery systems where their popularity convinces managers to sustain stocking programs, as typically ecological conditions would not permit self-sustaining populations (Patterson and Sullivan, 2013). Here the stocking represents the biological intervention, which also likely occurs in a spatially explicit manner (i.e., only "suitable" lakes are stocked).

9. Manual relocation ("rescuing") native salmonid populations in drought-ridden streams of western USA (Beebe, 2019). Intensive biological intervention may slow the restructuring of the desired state (native salmonid fish and fisheries).

10–11. Rare and unlikely to persist; no clear examples.

*12. In the Colorado River that flows through the Grand Canyon of the western United States of America, native cyprinid fisheries may be declining as additional water and hydroelectric requirements increase coupled with popular but non-native salmonid. Management options have tended toward extreme intervention (salmonid removals, flow alterations; see **Box 3**) (Runge et al., 2018).*

that is unsuitable for a species (Beebe, 2019), or efforts to sustain humback chub (**Box 3**). Such attempts may have a great resource cost, but could produce social and political support for a particular imperiled system that provides ecological benefits for other less threatened taxa (Moyle et al., 1992; Moyle and Moyle, 1995), or benefit future management and conservation efforts. For example, public support for declining (and now extinct) passenger pigeon *Ectopistes migratorius* populations paved the way for the United States Endangered Species Act. Discontinued management support for a socially highly valued system that is destined for collapse could result in a loss of public support and trust.

(vi) Fishery intervention—Management actions intended to alter the fishery may be warranted in states with antagonistic forces where ecological forces align with management objectives but are opposed by social forces [i.e., –/+ on desired systems (**Table 2**, cells 4–6), +/– on undesired states (**Table 3**, cells 7–9)]. Classic fishery intervention would be meant to prevent, or reverse overfishing, such as described by Post et al. (2008) in western Canada trout fisheries, or may be mounting for newer

TABLE 3 | Examples and likely viable management strategies for socioecological forces (rows) and resilience stages (columns) relevant for an undesired management focus.

Forces	Structuring	Structured	Restructuring
+ Social/+ Ecological	1. +/+ on a building undesired system. Smallmouth bass and growing catch-and-release fishery in Pacific Northwest coastal rivers, USA. **Spatially explicit planning** **Change mgmt. objectives**	2. +/+ on a stable undesired system. Catch-and-release oriented trout anglers and the whitebait fishery in New Zealand where undesired state is introduced salmonids. **Spatially explicit planning** **Change mgmt. objectives**	3. +/+ on a collapsing undesired system. Rare, likely driven by forces beyond the recreational fishery **Likely no viable mgmt. action**
– Social/+ Ecological	4. –/+ on a building undesired system. Unwanted establishing invasive Asian carp and anglers in the Mississippi River, USA **Biological intervention** **Spatially explicit planning**	5. –/+ on a stable undesired system. Public and sea lamprey in Great Lakes, USA. **Biological intervention** **Spatially explicit planning**	6. –/+ on a collapsing undesired system. Overfishing introduced Nile Perch in Lake Victoria in East Africa. Examples relatively rare. **Outreach and education** **Spatially explicit planning**
+ Social/– Ecological	7. +/– on a building undesired system. Angler introductions of non-native species in Spain; overfishing. **Outreach and education** **Fishery intervention**	8. +/– on a stable, undesired system. Non-native largemouth bass and anglers in Japan. **Outreach and education** **Fishery intervention**	9. +/– on a collapsing undesired system. Whirling disease disproportionately affecting non-native salmonids in northeastern United States of America. **Outreach and education** **Fishery intervention**
– Social/– Ecological	10. –/– on a building undesired system. Rare and unlikely to persist **N/A**	11. –/– on a stable, undesired system. Rare and unlikely to persist **N/A**	12. –/– on a collapsing undesired system. Rare **Little action needed**

1. System: Introduced and popular smallmouth bass fisheries (undesired system) in coastal rivers of Pacific Northwest, USA. Situation: In some rivers of Pacific Northwest, introduced non-native smallmouth bass have developed as a socioeconomically important recreational fishery that is desired by many anglers but may be undesired by management agencies seeking to preserve native salmonids (Fritts and Pearsons, 2004). The popularity of smallmouth bass with anglers, coupled with their apparent ecological advantage in these systems suggests either management intervention in select systems, or wholescale alteration of management objectives (i.e., to "desire" the building smallmouth bass state).

2. Non-native salmonids introduced to New Zealand waters are undesired (by some management agencies) because of their deleterious effect on the native whitebait (galaxiidae) populations (Lintermans, 2000). Non-native trout are popular sportfish for local and tourist recreational fishery that is largely catch-and-release. Managing for native fish in certain waters may be tenable.

3. No clear examples are apparent from primary literature, but a number of studies describe in passing the suspending of fisheries management actions associated with international conflict, such as World War II (Caddy, 2000).

4. Invasive Asian carp, which are not readily caught on terminal tackle, have rapidly expanding populations throughout the river basin and are outcompeting native species sought by recreational anglers. Relevant management actions include removal of invasive species or motivating fishery exploitation (Tsehaye et al., 2013).

5. Sea lamprey are considered a pest organism in the Great Lakes of North America, where lamprey have been associated with negative effects on desired salmonid species (Coble et al., 1990). Primary management actions include removal with the intent to eradicate or limit population.

6. Overfishing of introduced Nile perch Lates niloticus may correlate with increased smaller native fish traditionally targeted in Lake Victoria, East Africa. This example depends on agencies classifying Nile Perch as an undesired system, which is not likely unanimous (as many may prefer the introduced species for its economic effects (Mkumbo and Marshall, 2015). While spatial planning may be applicable in many systems, it may not be useful in this large lake that borders three countries.

7. Angler-introduced species in freshwaters of Spain may be leading to negative effects on wild fish (Elvira and Almodóvar, 2001). Another common, general example would be mounting overfishing, as apparently occurred in Northwest Canada's lake fisheries for salmonids (Post et al., 2008).

8. Management efforts are underway to eradicate largemouth bass in Japan because this invasive species has caused and is causing harm to native fishes (Nishizawa et al., 2006). Even so, the popularity of bass fishing in Japan continues to increase, especially among catch-and-release anglers from around the world.

9. Whirling disease disproportionately affected non-native rainbow trout and brown trout compared to salmonids native to northeastern United States of America, brook trout Salvelinus fontinalis and lake trout Salvelinus namaycush, and for a short time, it appeared that this disease might shift systems away from non-native trout (though these non-natives would have still been the desired system by many if not most management agencies; Hulbert, 1996). An alternative example would be cases where a nutrient enriched lake (undesired state) can be restored ecologically, but doing so would lower fishery productivity (i.e., anglers and social forces would prefer the enriched, undesired system state). This roughly was exemplified by the Kootenay Lake fertilization experiment in western Canada (Ashley et al., 1997).

10–12. Rare; no clear examples.

destination fisheries like peacock bass *Cichla* spp. and arapaima *Arapaima* spp. of Amazonia, goliath tigerfish *Hydrocynus* spp. of the Congo river basin, or tiamen *Hucho taimen* of Mongolia (Allan et al., 2005; Post et al., 2008; Jensen et al., 2009; Campos and Freitas, 2014; Lennox et al., 2018). Less common, but feasible fishery interventions would include encouraging overharvest of species associated with an undesired state (e.g., Asian carp *Hypophthalmichthys* spp. in the Mississippi River system; Galperin and Kuebbing, 2013; Varble and Secchi, 2013). This would likely involve melding classic fishery management actions (e.g., relaxation or elimination of harvest and gear restrictions) with outreach and education approaches to encourage different angler behavior, or perhaps supporting markets for commercial exploitation of the undesired species (Catalano and Allen, 2011; Nuñez et al., 2012). It should be noted that this induced-overfishing type of intervention might occur in system states and resilience stages typically characterized by biological intervention (e.g., **Table 3**, cell 4). Thus, the delineations of biological vs.

BOX 3 | A case study: The Grand Canyon, United States of America.

Managing for resilience when everything is complicated: the case of the Grand Canyon

A principle from resilience applications to natural resource management is the importance of probing models until they fail (Holling, 1973; Holling and Meffe, 1996). This can reveal tenuous assumptions that may lead to costly mistakes. It is prudent to confront the conceptual model we present here with an especially challenging and complicated scenario. One such example is the management of the fish and fisheries in the lower Colorado River as it flows through a series of iconic canyons (Glen, Marble, and Grand canyons) and wilderness reaches between Glen Canyon Dam and the western edge of Grand Canyon National Park upstream of Lake Mead in the western United States of America. These complexities include the following:

- Major alternations to river discharge due to large hydroelectric dams that provide power and water to millions of citizens
- Complex governance at interstate and international levels including seven recognized American Indian tribes.
- Multiple competing and likely alternative fish communities: native cyprinids including the endangered humpback chub *Gila cypha* and introduced non-native salmonids that support economically valuable recreational fisheries but may cause deleterious impacts to native fish communities (Korman et al., 2015). Expanding risk of range expansion from warmwater non-native species that may also have negative impacts to native species.
- Complex and competing interests of stakeholders including wilderness hiking and rafting, native fish, unique river ecosystem, hydropower production, and water storage and delivery.
- These interests all occur within an area that is the ancestral home to multiple American Indian Tribes who value the economic, cultural, and spiritual components of the region.

Classifying the system using our conceptual model

This system would clearly have multiple filters shaping the management foci—federal Endangered Species Act laws requiring action to prevent extinction of native fish, human well-being associated with continued production of electricity and in other parts of the system, drinking water, and American Indian rights (Melis et al., 2015). Beyond these, our conceptual framework would first consider the Grand Canyon system as separate desired and undesired system states. One desired system state would be the native cyprinid community. This would likely have some positive (humans preferring a "natural" systems) but also some negative social forces (humans preferring to catch non-native salmonids). Ecological forces currently would be negative because the altered flow and thermal regimes may allow non-native salmonids and other fish to out-compete native cyprinids (Coggins and Yard, 2010). So this would place the native cyprinid system state in either a synergistic eroding or restructuring stage (**Table 2**, cell 12), or, if one believes the social forces tip toward preserving native fish, in an antagonistic (+/–) restructuring stage (**Table 2**, cell 9). A separate desired state would be the non-native salmonids. This would largely represent the inverse of the native state—with positive ecological forces and either negative or positive social forces in likely a structured stage (so **Table 2**, cells 2 or 5).

Examining if the management advice makes sense

If the native cyprinid system is preferred, our conceptual model suggests that it should be pursued by biological intervention, spatially explicit planning, or a change in management objectives (**Table 2**, cells 9 and 12). Biological intervention does in fact occur, with non-native removals and flow alterations designed to improve habitat, but may forfeit some hydropower production (Runge et al., 2018). In addition to being logistically challenging, non-native removals have also been criticized by American Indian tribes, whereas flow alterations also impose costs and are unlikely to dislodge non-native species (Runge et al., 2018).

If the non-native system is preferred, the most likely state and stage would correspond to little management action (**Table 2**, cell 2) or at most attempts to change stakeholder perceptions or to adopt spatially explicit management (**Table 2**, cell 5). This does appear to largely match what has been considered (Runge et al., 2018).

Though the conceptual model appears reasonable for applying to even this complex system, two weaknesses are highlighted. First, the conceptual model does not explicitly force the user to consider how actions advised in the management pursuit on one desired state will affect those of another. This is implied by the recommendations for spatially explicit management (e.g., **Table 2**, cells 5 and 9), where the antagonistic nature of social and ecological forces would suggest doing different things in different places is ideal. Second, the conceptual approach does not provide specific advice for how to implement the broad management strategies suggested. This may be unfixable, as such detailed advice is unlikely useful across many systems. In the case of the Grand Canyon, the external filters (multiple sovereign states, legal mandates) describe a system too complex for agency-specific management and one in which no management decisions can reasonably reconcile the multiple objectives and values (Schmidt et al., 1998).

fishery intervention need not be rigid, and often biological and fishery interventions will be combined as a management strategy (e.g., removal of undesired non-native species could be combined with deregulating their harvest or restricting their voluntary catch and release).

(vii) Spatially explicit planning—The above management strategies may alone be insufficient to sustain desired and stave off undesired states. It may be necessary to consider spatially explicit planning—an application of marine spatial planning approaches of managing for different purposes in different places. This could be for two separate reasons. If social forces will oppose the management focus, it may make sense to designate certain discrete waters for whatever system stakeholders desire, even if it is counter to the management focus; for example, stocking non-native rainbow trout *Oncorhynchus mykiss* in some discrete waters while leaving other waters for native species. Alternatively, if social forces align with management foci, spatially explicit management may be needed if resources limit the biological intervention to a subset of waters. For example, resources for invasive species removal or native stocking may require focusing these actions on only some waters.

In summary, there seem to exist two groups of system state and resilience stages—those that do not require management action, either because (i) they already align with management objectives or (ii) are unlikely to occur and persist, and then those requiring management actions. Of the latter, there seem to exist relatively few options for shifting the system against the net effect of social and ecological forces. In short, managers may (iii) adopt a different management preference or focus, (iv) endeavor to change social norms, (v) engage in ongoing biological intervention (e.g., invasive species removal), (vi) engage in fishery intervention, or (vii) adopt landscape-level management approaches focusing on achieving different systems or states in different waters.

DISCUSSION

Operationalizing resilience provides management agencies a framework to (1) evaluate the state of a system (Beisner et al., 2003), (2) predict stage cycles a system state may undergo (Gunderson and Holling, 2002), (3) pinpoint which forces could shift a system to a different state (Walker et al., 2004), and (4) determine the management action (i.e., amount of disturbance) required to achieve a desired state (Suding et al., 2004). Management decisions, particularly in the developing world, are made with limited resources, and thus, opportunity costs must be considered. Incorporating resilience into management practices will enable diverse stakeholders the ability to make informed decisions that recognize costs, challenges, and process interactions associated with management goals and objectives.

This framework is designed to initially focus on singular management foci, but in many cases, management agencies will find themselves facing multiple objectives. How this should be handled will depend largely on how these multiple management foci interact. Some system states and resilience stages may complement each other. For example, if a given management focus requires little management intervention, recognizing this should make resources more available for management objectives. A realistic example might be in the southeastern United States of America, where the primary inland recreational fisheries management focus for most regions is ensuring a desired largemouth bass fishery is sustained. However, the ecology of largemouth bass combined with extreme voluntary catch and release angler behavior likely results in +/+ social and ecological forces on a desired state and structured stage. Management agencies in such situations may redirect some resources toward additional management foci, such as less prominent but still important fisheries, rare but untargeted fisheries, or groups of anglers who may be underserved (e.g., shore-based or minority anglers). Where multiple management foci do not complement in this manner, resources must be divided. The common tools for addressing these cases exist in decision science, from initial multi-attribute decision-making processes, to more modern Structured Decision Making procedures (Kleindorfer et al., 1993).

A particular but common case of managing for multiple system states simultaneously is where the desired states actively conflict with each other or compete. Competing objectives is no new challenge and is common in inland recreational fisheries (e.g., managing for native non-sport fish and non-native sportfish, or managing for high catch rates and trophy fish). Where there exist multiple discrete or near-discrete waters, the most likely way to address this is spatially explicit management that divides systems out and manages them with separate objectives. For example, managing for angler satisfaction through fish stocking whilst mitigating negative effects on wild fish stocks may be difficult to achieve within the same system (Pister, 2001). In this case, a subset of systems could be managed for anglers (i.e., stocked) and the remaining systems managed for wild stocks or genetic variation (i.e., not stocked). In the developing world, a subset of systems could be managed to serve food security needs (for recreational anglers and subsistence fishers) and others for recreational fishing tourism.

Of course, there are examples where a single or rather indivisible water hosts multiple competing management foci that are unlikely to be simultaneously achieved. For example, collectively managing for salmonids *Oncorhynchus* spp. and smallmouth bass *M. dolomieu* in Pacific Northwest rivers will likely be futile. A decision must be made to manage for either smallmouth bass, salmonids, or some other structured state. Pacific Northwest fisheries appear to be in a restructuring stage given a focal lens of salmonids, whereas they appear to be in a structuring stage given a focal lens of smallmouth bass. Anthropogenic alterations of habitat (e.g., dams) and climate change have led to an increase in smallmouth bass abundance; smallmouth bass consume salmonids and compete for available resources (Carey et al., 2011). A change in salmonid or smallmouth bass populations will likely lead to a different system state and resilience stage (i.e., top system predator), but the amount of management costs or disturbance required to shift the system from a "smallmouth bass" to a "salmonid" state will be drastically different from the management costs to shift the system from a "salmonid" to a "smallmouth bass" state. In a developing world example, collectively managing a gillnet-based food fishery and an exclusive tourist, trophy fishery for large *Labeobarbus* species in a large South African impoundment (Vanderkloof) will also likely be futile. This is not only because the emerging harvest fishery may drive the system into a restructuring stage, but also from a social perspective as extensive gillnetting and exclusive tourist angling destinations for trophy fishes are not compatible. Though there is increasing political pressure to expand the gillnet-based food fishery, the characteristically slow growth of the large *Labeobarbus* (Ellender et al., 2012; Gerber et al., 2012) will most likely not support a harvest fishery state and this restructuring will not lead to a highly resilient fishery. Ultimately, the choice of state and resilience stage in the developing world will need to consider how local communities will benefit most from a particular resource, and in this case, it is anticipated that managers will desire to restructure the fishery toward a trophy *Labeobarbus* state and encourage community development through active investment in the tourism industry. Regardless of whether a manager operates in the developed or developing world, placing decisions in a resilience management framework will afford practical guidance for difficult and complex socioecological problems such as these.

There exist a number of limitations of how this work can be used to better integrate resilience concepts in management. Despite our efforts, this work likely misses important developments of inland recreational fisheries taking place in certain parts of the world, especially Asia. Also, some of the broad management strategies described will be exceptionally difficult to accomplish. For example, changing stakeholder attitudes and behaviors through outreach and education will be exceptionally difficult. Though the tools to systematically affect human perceptions, attitudes, and actions are almost certainly more powerful now than they have ever been before (i.e., social networks, big data, and machine-learning approaches), the ethical and social capital implications of attempting to do so have not been well-explored. Similarly, changing management objectives is not easy and will require flexible governance systems and ample social, political, and economic capital. This is likely to engender pushback from managers. Another challenge is the uncertainty associated with assessing system states and resilience stages. The uncertainty associated with restructuring and potentially structuring stages introduces an additional level of uncertainty into management. If the stage of the system is unclear, the dynamic system must be evaluated and management goals established. If the emerging system is sufficiently novel, multiple tactics—social or ecological—may exist. In such instances, provided a sufficient time frame, managers may wish to employ adaptive strategies to select the desired management approach. This iterative process may result in an evolution of management objectives as the new system emerges.

Two deeper limitations require particular attention. First, the conceptual model implies managers can understand how social and ecological forces act on the system, which is necessary to define the system state. Sometimes this will be obvious, but other times, it may not be—especially when multiple stakeholder groups want and act in opposite ways (e.g., anglers preferring wild catch-and-release fisheries and those wanting put-and-take fisheries, or traditional recreational fisheries to supplement food and burgeoning destination-fishing intended to attract tourists). This leads to the second, deeper flaw with our conceptual model—it does not provide insight as to how to select one system focus over another (i.e., defining the management focus). This could be trivial in simple systems with homogeneous anglers and minimal conflict with non-anglers. But in other systems where multiple angler and non-angler stakeholders want fish or their habitat (e.g., water) for competing uses, it will be complex (Schmidt et al., 1998; Floyd et al., 2006; **Box 3**). And everywhere, the definition of focus will be affected by the power different stakeholder and governance entities hold (Daedlow et al., 2011, 2013; May, 2016). Unfortunately, we know of no agreed-upon metric whereby managers (of any natural resource) can determine which user group's desire should be prioritized. In many countries, this is evaluated by courts and litigation. Unable to resolve this limitation, we can only emphasize its importance.

Emerging from this work is the recognition of the role of spatial and temporal scale when considering resilience management of recreational fisheries; management of individual discrete waters may not require the same approach as management at a regional or landscape scale—at least, the latter would allow for some different approaches. A paradigm shift from water-specific management in isolation to water-specific management within the landscape context of other, surrounding waters (within and outside political boundaries of interest) is in order. In essence, design for adaptability with the explicit recognition that it is not possible to meet all socioecological needs within a single system. Having said this, we also recognize that at some time scale, all systems are in a panarchical cycle. There are many institutional procedures (e.g., license sales, political desires to provide similar opportunities among spatially distributed constituents) in place to reinforce regional management. Even so, we acknowledge that the potential costs (decision making, monitoring, and enforcement) of implementing a more detailed spatial management may be great. However, the cost of exploring such options is minimal and may greatly enhance the understanding of the socioecological system being managed. The challenge is to develop creative ways to think about management actions (habitat manipulations, stocking, regulations) and how they impact the resilience of a system by (1) breaking down resilience of social or ecological forces of an undesired state to allow the system to reorganize into a different and hopefully desired state and (2) reinforcing the resilience of social or ecological forces of a desired state to sustain the system in that state.

Systems could reside in multiple different system states and resilience stages within a management unit (e.g., regional fishery; Martin and Pope, 2011; Chizinski et al., 2014; Martin et al., 2017), which affords the opportunity to focus efforts on a subset of systems, perhaps based on ecosystem size (Kaemingk et al., 2019). Again, a resilience management framework would facilitate prioritizing which systems should be selected based on their system state and resilience stage as well as available resources. This becomes fairly straightforward if most systems are structured in desirable states (i.e., minimal inputs needed), and only a few are in a structuring or restructuring stages that will lead to undesirable states. Some United States management units have a small subset of waters infected by invasive mussels that can cause economical damage and ecological harm (Kraft and Johnson, 2000). Management efforts, albeit costly, could be prioritized to remove or prevent the spread of these mussels to other systems within a management unit.

SYNTHESIS AND LOOKING FORWARD

Viewing resilience as a characteristic of inland recreational fisheries is attractive for management and conservation efforts. Further categorizing these resilience characteristics provided a framework for operationalizing resilience management for conservation of inland recreational fisheries (**Figures 1, 2**, **Tables 2**, **3**) by recognizing the management strategies likely viable for given system states and resilience stages. Few options exist for shifting a fishery system against socioecological forces. In short, managers may (1) adopt a different ecological system as the management objective, (2) endeavor to change social norms, (3) engage in ongoing biological intervention (e.g., invasive species removal), (4) engage in fishery intervention, or (5) adopt landscape-level management approaches focusing on achieving different systems in different waters. The latter options are suitable under the greatest number of system-state and resilience-stage combinations and are uniquely relevant to inland recreational fisheries given the existence of discrete waters and the general inability of most fishes to traverse terrestrial environments.

We envision a future world in which management agencies developed resilience plans for desired and undesired states of their systems. The plans would identify and rank potential system states (including socioecological forces) and include potential actions to be implemented for each combination of resilience stage and system state. These plans would result in more efficient objectives and would actually prioritize actions that focus on sustaining desired system states rather than optimizing services of those states at any given time.

AUTHOR CONTRIBUTIONS

KP was invited to submit a contribution to this special feature and assembled the team of authors. EC, KP, MK, RA, and WMP devised the conceptual model presented herein. EC, MK, RA, WMP, WEP, OW, and KP contributed to the writing of the manuscript.

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