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FORUM

Fishing for Resilience

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Abstract
Management approaches that focus on social–ecological systems—systems comprised of ecosystems, landscapes, and humans—are needed to secure the sustainability of inland recreational fisheries without jeopardizing the integrity of the underlying social and ecological components. Resilience management can be useful because it focuses on providing recreational capacity for fishermen under a variety of conditions while assuring that the social–ecological system is not pushed to a critical threshold that would result in a new, undesired system regime. Resilience management is based on a system perspective that accounts for the possible regimes a system could manifest. It aims to enhance system properties that allow continued maintenance of the system in a desired regime in which multiple goods and services, including recreational capacity, are provided. In this forum paper, we provide an overview of the potential of a resilience approach to the management of recreational fisheries and highlight the scientific and administrative challenges to its successful implementation.

Recreational fishing connects aquatic ecosystems with human society. Fishery management is "manipulation of aquatic organisms, aquatic environments, and their human users to produce sustained and ever increasing benefits for people" (Nielsen 1999). Humans have harvested fish for more than 42,000 years (O'Connor et al. 2011), and recreational efforts have steadily increased during the last half century (Arlinghaus et al. 2002; Cooke and Cowx 2004, 2006; Swartz et al. 2010). Although fish are components of cultures and economies at local, regional, national, and global scales, societies have often ignored their importance to the health of aquatic ecosystems. Fishery management therefore historically focused on fish populations rather than on the ecosystems or landscapes in which those populations are embedded, with an emphasis on maximizing sustainable yield (Finley 2009) by preventing both growth (Schaefer 1954) and recruitment (Walters and Martell 2004) overfishing, though contemporary fishery management has begun to adopt an ecosystem emphasis (Cowx and Gerdeaux 2004; Pikitch et al. 2004). Since the mid-20th century, fishery management has engaged broadly with the social, economic, and ecological contexts of fish production. Even so, preventing overfishing remains a key component of fishery management in the recreational sector (Radomski et al. 2001; Post et al. 2002; Cooke and Cowx 2004, 2006) because management objectives, especially those related to participation levels, often cannot be achieved without high sustained yields.

Management of trade-offs between satisfied fishermen and healthy fish communities is needed to secure the social dimensions of recreational fisheries without jeopardizing the integrity of the underlying ecological dimensions. This requires that fishery management target the broader social–ecological system because the social and ecological components are interconnected and dependent on each other (Bottom et al. 2009; Allen et al. 2011a). By definition, the fishery is the part that mediates interaction between the social and ecological components (Figure 1). Managers need to understand the driving factors for both the

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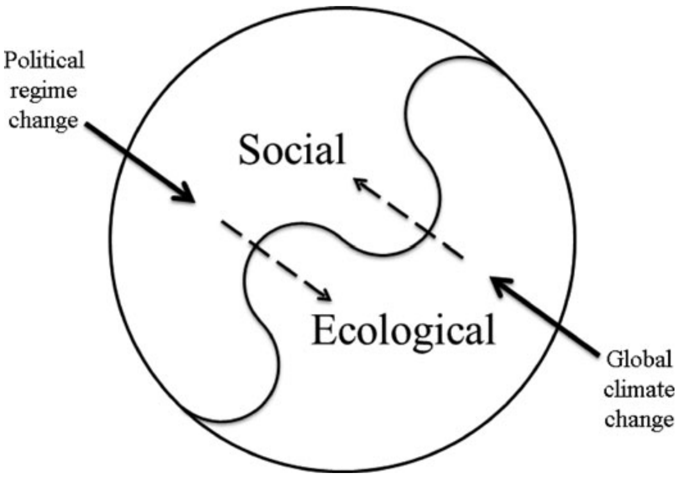

FIGURE 1. Schematic illustration of the interconnectedness and interaction between the social and ecological components of a fishery and the differential influences of two external forces—global climate change and political regime change. The solid arrows represent direct influences, the dashed arrows indirect ones. Thus, the figure illustrates the hypothesis that climate change has more influence on the ecological component, whereas political change has more influence on the social component.

social and ecological components—and the degree of coupling between them—to effectively manage the social–ecological system. For example, lakes with minor development of recreational fisheries are scattered throughout the Nebraska Sandhills and have loosely coupled social and ecological components, i.e., the interactions are relatively weak and often nonlinear and effects of one component on the other are often indirect (e.g., McCarraher 1960; Jolley et al. 2013). In contrast, reservoirs with major development of recreational fisheries are present throughout the Tennessee River and its associated tributaries and have tightly coupled social and ecological components (e.g., Ray 1949; Jakus et al. 2000). The management of social–ecological systems requires context-specific approaches (e.g., Olsson et al. 2004); recognizing the system properties inherent in the social and ecological components of each system is necessary.

Increasing connectivity through increased human mobility and the prevalence of social media, increasing human population, and increasing ecological perturbations (in the forms of biological invasions, climate change, and altered biogeochemical cycles) challenge our current management paradigms. We suggest that a resilience-based management approach offers viable solutions for the management of inland fisheries that are primarily targeted for recreation. Resilience theory has matured, and management actions to enhance the resilience of recreational fisheries can now be suggested, though there is still much to be learned about operationalizing resilience theory. Here we put resilience theory into context, present general management actions, and discuss the implications of managing inland recreational fisheries for resilience. We regard a recreational fishery as a system wherein two complex components, the social component and the ecological component (Figure 1), depend on each other and broadly interact along multiple spatial and temporal dimensions. This contrasts with traditional views, in which only interactions among biota, habitats, and human users are considered. Our view does not just simply move the human users into a social category and combine biota and habitats into an ecological category; people are obviously integral to both components. Further, our view explicitly recognizes that there are numerous, complex, and often nonlinear linkages between the social and ecological components of recreational fisheries (Holmlund and Hammer 1999; Hammer et al. 2003; Hunt et al. 2011) that need to be accounted for in the management of such fisheries. Independent enhancement of either social resilience or ecological resilience generally does enhance social–ecological resilience, though not as efficiently as a directed enhancement of the two together (Adger 2000); even so, it is often easier to think about and discuss the components of social–ecological resilience. We do envision rare cases in which increasing the resilience of one component could decrease the resilience of the other and possibly alter the resilience of the system as a result. This paper is not prescriptive; rather, it presents an argument for the applicability of a resilience approach to recreational fisheries and an exploration of the forms such an approach might take.

RESILIENCE

The concept of ecological resilience was first proposed by C. S. Holling in 1973. He recognized that systems perturbed beyond their capacity to recover could shift into an alternative state or regime. The term "regime" is preferred because it emphasizes the controlling processes of a given state of a system. The emphasis on alternative regimes was at odds with the prevailing ecological theory, which considered the relevant measure to be the return time following perturbation (i.e., engineering resilience; e.g., Pimm 1991). The emphasis on return time was based on the premise that a system will perform a specific task consistently and predictably, and thus it will reestablish performance if a disturbance occurs. The consequences of applying this type of thinking to the management of ecosystems have been extremely problematic, as the harvest of renewable resources such as trees and fish does not involve engineered systems with predictable and consistent outputs. Ecosystems do not have equilibrium regimes in which the opposing forces are in balance, as assumed by an engineering definition. Rather, ecosystems can exist in multiple regimes, within each of which the abundance and composition of the species comprising it may differ (Angeler et al. 2013b). Engineering resilience assumes that systems are characterized by a single equilibrium regime, and this assumption is inappropriate for complex adaptive systems such as ecological systems.

Following Holling's (1973) definition, we define resilience as a measure of the amount of change or disruption that is required to transform a system from one being maintained by one set of reinforcing processes and structures to one being maintained by a different set. When a system can reorganize itself into an alternative regime (i.e., shift from one stability domain to another due to, for example, overfishing of the top predators in an aquatic food web; Allan et al. 2005), the more relevant measure for ecosystem dynamics and the resulting management implications is ecological resilience (Holling 1973). For example, shallow lakes can occur in (at least) two alternative regimes, one characterized by clear water and macrophytes and another characterized by turbid water and algae (Scheffer 1997); the change from the former to the latter state may be forced by nutrient loading and maintained by the internal cycling of phosphorus in the new regime. Both regimes are stable, and major management intervention (such as stocking piscivorous fish and harvesting planktivorous and benthivorous fish; Drenner and Hambright 1999) is required to shift a lake from one regime to the other.

Resilience theory recognizes that ecological structure and dynamics are primarily regulated by a few processes (Gunderson and Holling 2002; Allen and Holling 2008) that operate at characteristic temporal and spatial scales (Holling 1992; Angeler et al. 2011). That is, processes that operate within and across scales reinforce each other in an ecosystem (Kauffman 1993), and these interactions lead to emergent phenomena such as resilience. For example, storms, toxic algal outbreaks, and predation determine structure and dynamics at scales ranging from meters to kilometers and from years to decades. In contrast, climate, geomorphologic, and biogeographic processes alter ecological structure and dynamics across hundreds of kilometers and millennia. Climate can reinforce the algal bloom dynamics in individual lakes which, in turn, collectively alter the phytoplankton dynamics across entire regions. Given that scale-specific patterns of social–ecological systems can be quantified (Allen et al. 2005; Nash et al., in press), we believe that a resilience approach to the management of ecosystems in general and recreational fisheries in particular can be a useful way to account for scale-specific patterns and processes.

MANAGING FOR RESILIENCE

Resilience management consists of actively maintaining a diversity of functions and feedbacks, steering systems away from critical thresholds at which they would tip into undesired regimes, and increasing the capacity of systems to cope with change. Achieving these goals is impossible without learning from past management actions and adapting to new social and environmental conditions (Biggs and Rogers 2003). A general goal of resilience management should be to generate improved understanding of the system in question rather than acquiring specific, detailed knowledge of its components (Folke et al. 2005). Resilience can be assessed with respect to subsystems (i.e., the social or ecological component and their subcomponents) as well as with respect to the social–ecological system as a whole. However, it is important that management specify what resilience, if any, is desired and should be monitored. For example, systems in undesirable regimes can also be resilient (Zellmer and Gunderson 2009). In such cases, the manager's goals are to weaken the resilience of the undesired regime, transform the system to a desirable regime, and then strengthen the resilience of that regime. The core of resilience management is thus (1) to anticipate potentially unwanted shifts in a desired regime and to take actions to prevent them, (2) to maintain a diversity of system elements and feedback interactions that will keep a system within a particular desired regime that provides desired goods and services, and (3) to reduce the likelihood of unwanted regime shifts by increasing the ability of the social–ecological system to cope with novel situations. Measuring resilience is problematic, and most of what we have learned in this area has come from comparative case studies (Anderies et al. 2006). In the case of inland, recreational fisheries, there are thousands of replicate systems around the globe and numerous management approaches are being implemented. Identifying the mechanisms underlying past fishery collapses—and the thresholds that were exceeded—is a critical first step to applying a resilience approach.

IMPLEMENTING A RESILIENCE APPROACH TO FISHERY MANAGEMENT

Appropriate management strategies vary with the degree of uncertainty associated with the process that is to be managed and the ability of the manager to manipulate the system (Peterson et al. 2003). Traditional approaches work well when uncertainty is low and the manager is able to manipulate the system. More flexible management and policy approaches, coupled with scenario planning (Peterson et al. 2003), are needed when either uncertainty or the difficulty of achieving the desired manipulation is high. This is more typical with the social and ecological components that compose most recreational fisheries. Resilience management cannot be adopted effectively in the absence of science and monitoring, and it will not be successful if the interplay between society and ecosystems is ignored. Resilience management is most effective when the key elements and interactions in the system have been described, the key uncertainties have been identified and reduced (where possible) through management experiments, and the potential perturbations have been evaluated in advance (e.g., scenario planning).

Social systems and ecosystems have high complexity, and this is increased when they are considered together. Consequently, the implementation of a resilience approach and the choice of management strategies will be highly context specific. Recommending specific management schemes is therefore ill-suited to resilience approaches to management. Even so, we believe that it is now possible and appropriate to suggest management goals and actions that can enhance the resilience of recreational fisheries (Table 1). Many of these actions are already being undertaken by managers. However, these actions are often taken in relative isolation and in the absence of a unifying framework; resilience theory provides such a framework for management actions. The following are some key issues that could be considered by scientists, administrators, and managers who wish to manage inland recreational fisheries for resilience.

TABLE 1. Some management goals and actions, with associated barriers and benefits, for enhancing the resilience of recreational inland fisheries.

Goal	Actions	Barriers	Benefits
Identify stable regimes, thresholds, and leading indicators	Identify key driving factors of systems in which thresholds might exist Formalize conceptual models for specific recreational fisheries Search scientific literature to identify what is known and unknown Formalize alternative stable regimes specific to recreational fisheries	Insufficient knowledge of system dynamics Insufficient funds for monitoring	Important first step toward managing recreational fisheries for resilience Avoids shift of aquatic system to undesirable regimes
Identify critical scales	Clearly identify the focal scale of interest and linkages to other scales Incorporate temporal and spatial scales in conceptual models	Insufficient knowledge of system dynamics	Important step toward managing recreational fisheries for resilience
Manage water bodies as networks within the context of watersheds	Incorporate potential mutualistic and antagonistic interactions among water bodies in water body–specific management plan	Regulations would necessarily be complicated Requires knowledge of fishermen–water body networks	Spatially mediates fishing pressure to avoid degradation of individual water bodies by spreading risk throughout the region Diversification in fishing pressure and associated harvest among water bodies
Manage aquatic communities	Develop objectives that focus on trophic interactions and food web dynamics Utilize adaptive management to experimentally test new regulations	Funding tied to game fish Community interactions often poorly understood	Provision of broader ecosystem services Diversification in pressure and direction of associated harvest toward target species

Identify potential alternative stable regimes, thresholds, and leading indicators.—Successful resilience management will need to consider what alternative regimes might exist for the social and ecological components of a fishery. A regime shift occurs when a system exceeds a threshold. For example, an economic policy that promotes the conversion of pastureland in the watershed of a reservoir to row crops or confined animal feeding operations is likely to lead to a regime shift in the ecological component of the reservoir fishery. Intensive row-crop agriculture in the USA yields N:P stoichiometry at the high levels observed in pristine headwaters and open oceans, whereas intensive animal agriculture yields N:P stoichiometry at the low levels usually associated with cyanobacteria blooms (Arbuckle and Downing 2001). Elemental demands for fish growth depend directly on the stoichiometry of the elements in body tissues, and thus changes in the availability of elements could ultimately result in changes to the composition of the fish community (McIntyre and Flecker 2010). Further, changes in the composition of the fish community could result in changes in elemental cycles (because ingested elements that are not incorporated into body tissue must be excreted), thus providing a possible negative feedback mechanism that leads to further change in the composition of the fish community (Quirós 1998; McIntrye and Flecker 2010).

The explicit identification of thresholds is valuable because awareness of a possible trap is the first step in avoiding it. That is, determining alternative configurations of the linked social and ecological components (Walker and Meyers 2004; Cinner 2011) and then understanding how a system may be transformed are necessary first steps in managing social–ecological systems for resilience. The Resilience Alliance has created open-access workbooks (http://www.resalliance.org/index.php/resilience_assessment) designed to help mangers identify cross-scale linkages and potential alternative states and thresholds. Here we define an ecological threshold as the point at which there is an abrupt change in an ecosystem quality, property, or phenomenon or that at which small changes in one or more external conditions produce large and persistent responses in an ecosystem (Fagre et al. 2009). Put another way, an ecological threshold or change point is defined as the point at which there is an abrupt change with respect to an environmental factor or stressor that strongly modifies a defined system or community (Solheim et al. 2008). The thresholds between alternative regimes may be marked by changes in the direction or intensity of feedbacks or by increases in the variance of key parameters (Carpenter and Brock 2006; Wardwell and Allen 2009). Leading indicators include increasing variance (Carpenter and Brock 2006), critical slowing (Scheffer et al. 2009), and decreasing

Fisher information (Karunanithi et al. 2008). Fisher information and other variance indices work well when a large amount of data are available and there is uncertainty as to which variable is key; other approaches require the a priori identification of key parameters (Andersen et al. 2009). Of particular interest is the identification of "traps," i.e., undesirable, self-reinforcing system configurations from which the system may find it difficult to return to a desired regime because of hysteresis or loss of capital (Carpenter and Brock 2008). Examples include the eutrophic states of lakes exhibiting hysteresis and poverty traps caused by the degradation of critical natural resources.

Consider the cross-scale resilience model.—This model posits that resilience is enhanced with increasing diversity of function within scales and redundancy of function across scales. The resilience of ecological processes, and therefore that of ecosystems, depends on the distribution of the functional traits of species within and across scales (Peterson et al. 1998). If animal species that are members of the same functional group operate at different scales, they provide mutual reinforcement that contributes to the resilience of a function while minimizing competition among species within the functional group. For example, zooplanktivores in a lake often include zooplankton, insects, fish, and birds, all of which prey on zooplankton at different spatial and temporal scales; this minimizes interspecific competition, and the elimination of one of these predatory groups does not eliminate all predation on zooplankton. Resilience is enhanced by imbrications of ecological function among species of different functional groups that operate at the same scales and the response diversity of members of the same functional group within scales (Elmqvist et al. 2003), which provide a robust response to a diversity of perturbations that complements the cross-scale redundancy of responses. For example, community change in subarctic lakes has been shown to be scale specific, with a subgroup of littoral invertebrates tracking slow changes of regional environmental conditions and other subgroups responding to faster processes that are unrelated to environmental change (Angeler et al. 2013a). In this example, resilience emerges from the cross-scale reinforcement of the functional feeding attributes of the invertebrates, that is, feeding attributes that were present across scales and redundant within each scale of temporal change observed. In practice, this means that invertebrates responding to fast changes may safeguard the whole system from the potential loss of functions at a scale on which the impacts of global change can be substantial, thereby helping to stave off regime shifts. In this example, the cross-scale resilience model has been tested by inferring ecological patterns that manifest themselves at distinct temporal scales. Strong links have also been found in the scaling of functions within and across scales using the body size of animals (Allen et al. 2005). Implementing the cross-scale resilience model requires identification of the scales present in the system (see Allen et al. 2005; Nash et al., in press) and determination of the functional roles of the components of the system. Such approaches have a long history in ecology but are less well developed in the social sciences (though the cross-scale resilience model has been applied to nonecological systems such as businesses; Garmestani et al. 2006).

To apply the cross-scale resilience model to the social components of recreational fisheries, we must understand the functional roles of stakeholder groups within managed societies. There is a need to diversify fishing pressure within lakes and create alternative opportunities and redundancies for recreation. This could be accomplished by working with the existing diversity of stakeholders to provide fishing opportunities that are culturally sensitive. Enhancing resilience is important, and this may be possible by maintaining the patterns of distribution of societal functions within and across scales. Ultimately, matching the scales of social processes with the scales of ecological processes can contribute to an increase in social–ecological resilience, though this may be difficult to achieve (Cumming et al. 2006; Wilson 2006). Even so, we are hopeful because resilience in social systems is currently an extremely active area of research.

Identify critical scales.—We need to understand scale-specific processes and structures in managed systems. The identification and recognition of predominant temporal (frequencies) and spatial scales and cross-scale interactions is central to managing for resilience (Angeler and Johnson 2012; Angeler et al. 2013a; Nash et al. 2013) because the impacts of global change are most evident only at specific scales. Some of these scales are very broad in space and unfold slowly over time (e.g., changes in nutrient deposition rates), potentially leading to a loss of critical functional processes and thus resilience over time. However, these broad scales are difficult if not impossible to manage. Managing systems to reinforce ecological structures and processes at scales that are relatively unaffected by global change could increase the overall resilience of the system (Angeler et al. 2013a).

In a fishery context, the temporal scales of interest for fishing pressure could include the frequency and duration of recreational fishing trips and the relationship between trip length and frequency; the particular scales of interest will depend on the system being investigated and the set of alternative states that are possible. Similarly, the relationships between water body size and fishing trip distance and duration are important. The administrative scales at which policy and regulatory decisions are made are also critical, though these scales rarely correspond to the relevant ecological scales (Conroy et al. 2003; Cumming et al. 2013).

Manage water bodies as integral networks of watersheds.—The features of a water body are a function of topography and precipitation, mediated by the human-built environment and climate. Thus, watershed characteristics are as important for fisheries managers to consider as the water body in question because these characteristics influence recharge rates, pollutant fluxes, and nutrient loads (Carpenter et al. 1998; Bennett et al. 2001). Changes in the landscape will require modification to the current approaches to management. A shift in a landscape from one dominated by prairie to one dominated by agriculture requires managers to establish working relationships with farmers, cooperatives, and policy makers and to explicitly consider past, present, and potential future policies regulating agriculture. Likewise, a shift in a landscape from one dominated by agriculture to one dominated by a suburban environment requires managers to establish relationships with community activists, mayors, business owners, and neighborhood associations and to consider past, present, and potential future policies regulating zoning and development.

Although water bodies embody compartmentalized ecosystems, humans interact with water body networks rather than water bodies in isolation (Carpenter and Brock 2004). Recreational fishermen are highly mobile, with access to social media that can communicate changing fishing conditions and alter fishermen's behavior very quickly (Martin et al. 2012). Who is fishing with whom, how often, and what motivates them? Understanding the participation patterns and motives of fishermen within a regional fishery and identifying primary and secondary substitute water bodies will improve managers' ability to lure fishermen from overutilized water bodies to underutilized ones (Martin and Pope 2011). Understanding the spatial arrangement of water bodies within regional fisheries (or the spatial arrangement of habitats within watersheds; Bisson et al. 2009) will augment a landscape approach. Managing the connectedness of water bodies will ensure a balance, such that they are not too isolated or too connected. This is perhaps best achieved by the development of explicit measurements of functional connectivity among and within water bodies, which is likely influenced (at a minimum) by fishing regulations and stocking practices.

Manage fish populations and recreational fishermen as components of aquatic communities.—Scientists are calling for a change in the way we think about harvesting the surplus production of fish from wild populations; harvests that target species and sizes of individuals in proportion to the composition and size distribution of an aquatic community (Berkeley et al. 2004; Anderson et al. 2008; Hsieh et al. 2010; Garcia et al. 2012) and that occur in space and over time in proportion to the spatial and temporal distributions of the desired aquatic community have the greatest probability of keeping aquatic communities in a desired regime. Managers of ponds that contain a simple fish community (e.g., Bluegill *Lepomis macrochirus* and Largemouth Bass *Micropterus salmoides*) have long recognized the need for a balanced approach, often recommending that the biomass of Bluegills harvested annually be an order of magnitude greater than the biomass of Largemouth Bass harvested annually (Swingle and Smith 1942a). Failure to implement a balanced harvest often leads to stunting of the Bluegills (Swingle and Smith 1942b) or a regime shift in the fish community that leads to shifts in the reproductive ecology of Bluegills (Beard et al. 1997; Aday et al. 2002) and altered interactions with Largemouth Bass (Turner and Mittelbach 1990). Unfortunately, it is unclear how one should expand this harvest approach to larger water bodies with complex fish communities. We contend that new fishing regulations focused on species interactions, the patterns of co-occurrence among the species caught by fishermen, water body size, and the desired regime of the system are needed to effectively maintain stable aquatic communities. As in the resilience approaches in other natural resource disciplines, flexibility and adaptability (which, for the sake of clarity, are often forgone in favor of consistency) are the keys to maintaining desired aquatic systems.

The management of the social aspect of fisheries will need to shift from being implicit to being explicit. Management objectives could specify social measures, such as satisfaction, and encourage shifts in fishing pressure from one water body to another when such movement meets management goals. Resource policies that are implemented without consideration of the social consequences often generate conflict and lead to poor compliance (Sutinen 1998; Sutinen and Kuperan 1999; Hiedanpaa 2005), which in turn undermines resource sustainability (Maiolo et al. 1992; Roe 1996; Hampshire et al. 2004). Understanding the responses of resource users as well as those of the general public is central to the effective management of recreational fisheries (Marshall and Marshall 2007). Political heterogeneity and connectivity may either enhance or reduce the resilience of social systems, depending on the governmental structure and the frequency and degree of political regime shifts. Identifying processes and their scale of influence is critical for successful resilience management. Management often focuses on small-scale processes, ignoring meso- and large-scale ones, which can have severe consequences over longer periods.

There is a need to develop recreational specialization by individual fishermen and encourage recreational diversification among fishermen. Specialization usually produces greater political involvement of participants (Vaske and Donnelly 1999), along with an increased conservation ethic (McFarlan and Boxall 1996). Diversification provides recreational fishermen greater opportunities for participation when ecological components are dynamic. Managers can facilitate specialization by individual fishermen and diversification among fishermen by providing 5-year or generational forecasts of fish abundances and size structures to them. Managers may then adjust their actions with respect to the social component based on the relevant dynamics of the ecological component. Both the social and economic contexts need to be considered because fishermen face physical and financial constraints that might challenge the desired adjustments of the social scale to those underlying the ecological component. To that end, managers should consider the development of recreational portfolios (Tay et al. 1996; Ma et al. 2009) that incorporate multiple scales and activities, such as the inclusion of various recreational activities (e.g., fishing, reading, and water skiing) and various types of recreational fishing (e.g., gear and species specialization). It is also important in the development of recreational portfolios to consider the demographics of participants, especially in areas with aging populations (Chen and Sun 2012).

Modify regulations so that there is flexibility in science-based application.—A fundamental ecological problem with fishing is that, in addition to removing biomass, it truncates the age and size structures and reduces the spatial heterogeneity of exploited populations because fishermen usually target large (and therefore old) individuals, which likely inhibits the ability of those populations to withstand environmental variability (Berkeley et al. 2004; Anderson et al. 2008; Hsieh et al. 2010; Garcia et al. 2012). A fundamental social problem is that regulations need to be simple and rigid for effective law enforcement. This problem is exacerbated by the mobility of recreational fishermen, who respond nearly instantaneously to increases in the size of fish populations (Carpenter and Brock 2004; Martin and Pope 2011). A one-size-fits-all approach to regulations is inappropriate for recreational fisheries given the temporal and spatial dynamics in fish populations and fishing pressure. Temporal and spatial flexibility in the application of regulations must be granted to regional managers; doing so will likely increase their creativity with respect to regulations. Achieving this kind of flexibility may require a regime shift in the political system because managers are bound by statutes, which frequently allow regulation only for the purpose of conservation.

Effective management also requires an understanding of people's need to maintain sustainable aquatic communities. Managers of commercial fisheries have gauged some of the social consequences of policy options by measuring four key resilience attributes of commercial fishermen: their perception of the risk associated with change; their ability to plan, learn, and reorganize (adaptive capacity); their perception of their ability to cope with changing conditions; and their level of interest in change (Marshall and Marshall 2007). This approach is directly applicable to recreational fishing, though it is likely that there are different key attributes for recreational fishermen. Resource users require financial and emotional flexibility and a positive perception of policy change in order to support and comply with policy changes (Marshall and Marshall 2007). Managers can enhance the ability of recreational fishermen to cope with a policy change by developing fishermen's skills to plan and adapt prior to implementation of the change. For managers to successfully apply resilience management, recreational fishermen will need to be actively engaged in managing the resources they use; an active program of adaptive co-management and governance is encouraged.

Adopt adaptive management.—This approach is critical to resilience management because it focuses on learning and reducing uncertainty (Allen et al. 2011b). An important part of learning is acquiring intimate knowledge of the underlying hypotheses that drive management, the management activities that were undertaken, and the data that were collected for assessment. Unlike the traditional trial-and-error approach, adaptive management has an explicit structure, including careful elucidation of goals, identification of alternative objectives and hypotheses about causation, and procedures for the collection of data, followed by evaluation and reiteration. This experimental approach to management enhances learning by formally treating management actions as hypotheses and putting them at risk. For example, we might hypothesize that fish stockings, especially those of catchable-size fish such as Rainbow Trout *Oncorhynchus mykiss* during winter in urban environments, will increase the fishing pressure on a water body for a week or two. We might also hypothesize that implementation of more restrictive regulations, such as an increase in the minimum length limit for Walleyes *Sander vitreus* from 41 to 53 cm, will decrease the fishing pressure on a water body for several months or perhaps even years. It would remain unclear, however, what the overall effect would be if both of these management actions were implemented simultaneously. A well-thought out application of various changes in stockings and regulations across water bodies within a regional fishery would provide a robust test of our two hypotheses.

Though adaptive management is a potentially powerful tool for fisheries managers, it has seldom been adopted, even when mandated by statute. There is a multiplicity of reasons why agencies and managers have not embraced adaptive management, but according to Walters (2007), there are three primary ones: lack of resources, the unwillingness of managers to acknowledge uncertainty, and lack of leadership. Another important reason is lack of appreciation of the need to follow through with an experiment even if things seem to be going wrong. After all, reacting when things go wrong is part of being a prudent resource manager. Failing now in hopes of gaining knowledge to do better in the future is an extremely difficult sell, both to managers and fishermen. Crises in the form of failed management can create opportunities for the development of novel approaches and serve as catalysts for changes in human perceptions. Adjusting social expectations in response to changing environmental conditions can help social–ecological systems avoid crossing an unwanted ecological threshold (Forbes et al. 2009). It may be critical to involve stakeholders, to have them verbalize their mental models of the social and ecological components as well as their relationships with and influence on those components and to envision alternative scenarios of future conditions (Andrade 2009; Browne et al. 2009). Indigenous peoples may have vastly different mental models and objectives for fishery management, yet their knowledge, which is frequently overlooked, can be critical (Berkes 2008; Campbell and Butler 2010).

The key is appropriate application of adaptive management; such management is most appropriate when controllability and uncertainty are both high. Managers of inland-water fisheries have an advantage generally unavailable to wildlife managers: an abundance of replicate, compartmentalized ecosystems of tractable size with which to experiment, namely, different lakes and reservoirs. Active adaptive co-management that genuinely involves stakeholder groups in decision-making processes is superior to passive adaptive management that does not involve such groups. Adaptive governance (i.e., collaborative, flexible, and learning-based issue management across different scales) connects individuals, organizations, agencies, and institutions at multiple organizational levels, which tends to minimize the need for and costs of conflict resolution (Folke et al. 2005).

Adaptive management is not a panacea, and it is important to know when it is not suitable. As an example, one of the primary impediments to decision making is the conflict of values among stakeholders. In this situation adaptive management may have little to offer, and employing it can become little more than a delaying tactic that avoids the difficult challenges of developing effective institutional and governance structures to resolve disputes over values. Nor is an adaptive approach needed if the available management choices are insensitive to structural sources of uncertainty. Finally, the failure of management choices to discriminate among competing system models means that adaptive management will not result in learning, which is an essential aspect. Decision analysis provides a systematic framework for exploring these issues, and it is difficult to imagine how adaptive management could be planned or implemented absent this structure.

OPERATIONALIZING A RESILIENCE APPROACH TO FISHERY MANAGEMENT

To facilitate the application of management for resilience in recreational fisheries, we discuss the example of a regional fishery (Martin and Pope 2011) located within the Republican River watershed, in which we believe that operationalization of the items listed above could be achieved. In this example, a series of human interventions degraded the ecological component, fragmenting it and causing a potentially irreversible shift in the ecological regime. The Republican River is formed by the confluence of the North Fork Republican River and the Arikaree River in Dundy County, Nebraska; it also joins with the South Fork Republican River in Dundy County. All three tributaries originate in the High Plains of northeastern Colorado. The Republican River flows generally eastward along the southern border of Nebraska and then southward into Kansas. It joins the Smokey Hill River in Geary County, Kansas, to form the Kansas River. Drought in the early 1930s followed by a flood in 1935 that killed 113 people created the political desire to regulate the Republican River basin, which resulted in the creation of nine multipurpose reservoirs (Bonny Reservoir in Colorado; Enders Reservoir, Harlan County Lake, Harry Strunk Lake [Medicine Creek Reservoir], Hugh Butler Lake [Red Willow Reservoir], and Swanson Reservoir in Nebraska; and Keith Sebelius Lake, Lovewell Reservoir, and Milford Reservoir in Kansas) and six irrigation districts. Allocation of water from the Republican River is governed by a tristate agreement known as the Republican River Compact, which was adopted in 1943. In addition to these federal projects, substantial groundwater development has occurred in this basin.

In 1972, there were 37 identified fish species in the watershed and 729 km (∼40%) of streams were classified as environmentally degraded, mostly due to the withdrawal of water for irrigation (Bliss and Schainost 1973). As a result of agricultural overdevelopment (i.e., overappropriation of groundwater for crop irrigation), current groundwater and surface water flows are substantially lower than circa-1970 flows throughout the basin (Szilagyi 1999, 2001). This has been attributed to changes in vegetative cover, water conservation practices, and the construction of reservoirs and artificial ponds in the basin as well as to cropland irrigation, most of which increased water evaporation over the basin (Szilagyi 1999, 2001).

There are likely several alternative stable regimes for reservoirs within the Republican River basin. These reservoirs have two different sources of inflow: groundwater and runoff from precipitation. They were originally dependent on these sources to be refilled after providing water for irrigation. However, increases in the number of irrigation wells (especially in Nebraska) have depleted the groundwater levels in the basin (Burt et al. 2002; Wen and Chen 2006), such that most of these reservoirs no longer completely fill. During most years of the last decade, the water flows into Enders, Red Willow, and Swanson reservoirs were insufficient for irrigation. Conversely, the water flows into Medicine Creek Reservoir were sufficient for irrigation during the summer months in all years. This difference in inflows and consequent irrigation practices has created at least two different regimes—one with low inflows that results in few years with irrigation withdrawals and hence minimal intra-annual fluctuation in the water level and one with higher inflows that results in many years with irrigation withdrawals and hence maximal intra-annual fluctuation in the water level. These different water regimes create very different habitats (with more established vegetation, larger mean substrate size, and lower turbidity in the reservoirs with minor intra-annual fluctuations in the water level), with important ramifications for fish and invertebrate communities through population and predator–prey dynamics, which ultimately affect the experiences of recreational fishermen. Understanding these differences is critical for establishing appropriate management objectives with respect to the recreational fisheries of these reservoirs. More importantly, identifying the thresholds for the transition from frequent to infrequent annual irrigation withdrawals is needed in order to know when management objectives should be reversed (e.g., from a focus on limnetic sport fishes to a focus on littoral ones).

Unfortunately, there are no formally recognized scales for management objectives for the recreational fisheries within the Republican River basin, though there are certainly implied or assumed scales. We believe that the development of explicit objectives would be a valuable exercise for management. Temporally, these scales should include (at least) 1, 5, 10, and 50 years; spatially, they should permit comparisons within reservoirs (e.g., between riverine and lacustrine zones [Thornton 1990)]), among reservoirs, within regions and the political districts of the management agency, and across the political districts of the management agency and state boundaries.

Within the Republican River basin, there is some formal recognition by fisheries managers of reservoirs' locations within the physical landscape. Unfortunately, there is no formal recognition of their locations within the human landscape. We believe that comparisons of the landscapes (of all types) among reservoirs within the Republican River basin—with explicit statements of their similarities and difference—would be another valuable exercise for management. Even more valuable would be explicit predictions (whether correct or not) of the potential changes to these landscapes in the next 10–50 years.

Intensive surveys of fishermen, which is an important step toward management for resilience in recreational fisheries, have been undertaken for the recreational fisheries within the Republic River basin. The intent of these surveys is to gain better understanding of the current composition of fishermen that includes their demographics, skills, desires, and motives. This baseline information could be used to assess the degree of success in achieving management objectives. Of course, that comparison requires explicit management objectives with regard to the abundance and composition of recreational fishermen.

CONCLUSION

Is managing fisheries for resilience a superior approach? We believe so, but we acknowledge that this approach is currently untested and likely not without burden. The breadth of a resilience approach needs to reflect the complexity and multidimensionality of the interactions between the social and ecological components—which is a substantial impediment to the successful implementation of management for resilience. Even so, the strength of resilience management is that complexity can be addressed and explicitly incorporated into management decisions through implementation of a learning and adaptation process wherein hypotheses about social and ecological resilience are rigorously tested in management experiments. This is probably best accomplished by testing small pieces individually rather than by trying to test the entire concept at once, in part because no single management action is expected to enhance the resilience of all components or scales of a recreational fishery. The measurement of responses must be scale appropriate; we suggest that two social scales (fisherman groups and society) and three ecological ones (fish population, fish community, and aquatic ecosystem) are appropriate initial focal responses. This experimentation also demands control systems that are not subjected to management for resilience.

There are trade-offs between functional redundancy and functional diversity for both the social and ecological components of a recreational fishery. Further, the exact natures of these trade-offs are mediated by spatial variation, including location, context, connectivity, and mobility (Cumming 2011). For this reason, it is difficult to predict whether a regional fishery that consists of a single large (>25,000-ha) water body has greater resilience than a regional fishery that consists of 20 small (<200-ha) water bodies. A large water body would likely have greater species richness than 20 small water bodies in a given region. On the other hand, the 20 small water bodies would likely have greater functional redundancy. Similarly, a large water body generally draws recreational fishermen from greater distances than does a small water body. Thus, it is unclear whether management for resilience would be easier in a regional fishery with one large reservoir, two medium reservoirs, or 20 small reservoirs.

Like commercial exploitation of aquatic resources, recreational fisheries can lead to ecosystem degradation and collapse. Over time, the necessity for major intervention is reduced and the overall long-term sustainability of recreational fisheries is increased using the resilience approach. Management for resilience not only focuses on ecosystems but also targets both social and ecological components in a combined way. To achieve social–ecological resilience in recreational fisheries, managers are encouraged to focus on aquatic communities, landscapes, networks of water bodies within watersheds, and functional responses to people's needs. Administrators are encouraged to modify regulations and adopt adaptive management. Scientists are encouraged to identify alternative stable regimes, thresholds, and leading indicators (along with their critical scales) in the context of the cross-scale resilience model.

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