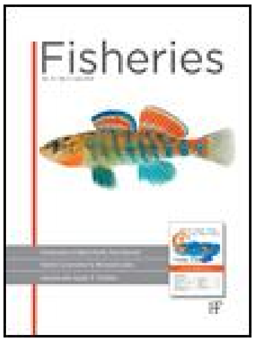

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FEATURE

ADAPTING INLAND FISHERIES MANAGEMENT TO A CHANGING CLIMATE

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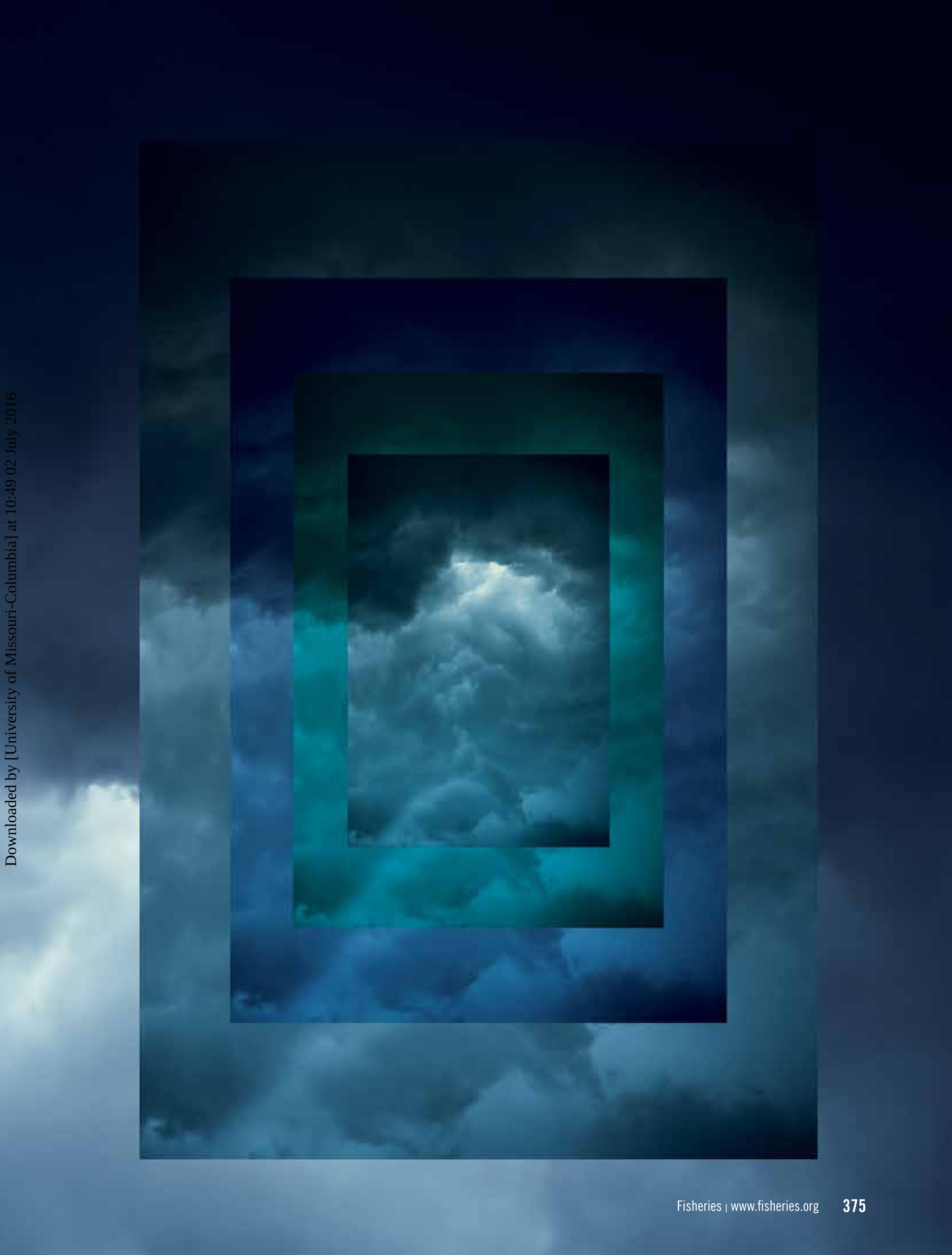


Natural resource decision makers are challenged to adapt management to a changing climate while balancing short-term management goals with long-term changes in aquatic systems. Adaptation will require developing resilient ecosystems and resilient management systems. Decision makers already have tools to develop or ensure resilient aquatic systems and fisheries such as managing harvest and riparian zones. Because fisheries management often interacts with multiple stakeholders, adaptation strategies involving fisheries managers and other partners focused on land use, policy, and human systems, coupled with long-term monitoring, are necessary for resilient systems. We show how agencies and organizations are adapting to a changing climate in Minnesota and Ontario lakes and Montana streams. We also present how the Florida Fish and Wildlife Commission created a management structure to develop adaptation strategies. These examples demonstrate how organizations and agencies can cope with climate change effects on fishes and fisheries through creating resilient management and ecological systems.

Adaptación del manejo de pesquerías continentales a un clima cambiante

Los tomadores de decisiones en materia de recursos naturales tienen la tarea de adaptar el manejo a un clima cambiante, y al mismo tiempo sopesar entre los objetivos de corto plazo y los cambios de largo plazo en ecosistemas acuáticos. Esta adaptación requerirá desarrollar tanto ecosistemas como sistemas de manejo resilientes. Los tomadores de decisiones ya cuentan con herramientas para desarrollar o asegurar sistemas acuáticos y pesquerías resilientes, tales como manejo por cuotas y por zonas riparias. En virtud de que el manejo de pesquerías a menudo implica la interacción entre varias partes interesadas, las estrategias de adaptación que involucran a manejadores de pesquerías y otros participantes con intereses en el uso de la tierra, en la política y en sistemas humanos, en conjunto con un monitoreo de largo plazo, son elementos indispensables para constituir sistemas resilientes. Se muestra cómo organizaciones y agencias de los lagos de Minnesota y Ontario y en los ríos de Montana, ya se están adaptando a un clima cambiante. También se muestra cómo la Comisión de Pesca y Vida Silvestre de Florida creó una estructura de manejo con el objeto de desarrollar estrategias de adaptación. Estos ejemplos demuestran cómo las organizaciones y agencias pueden responder a los efectos del cambio climático en materia de peces y pesquerías, a través de la creación de sistemas ecológicos y de manejo resilientes.

Adapter la gestion des pêches continentales à un climat changeant

Les décideurs des ressources naturelles sont mis au défi d'adapter sa gestion aux changements climatiques tout en équilibrant les objectifs de gestion à court terme avec des changements à long terme dans les systèmes aquatiques. L'adaptation exigera de développer la résilience des écosystèmes et de créer des systèmes de gestion souples. Les décideurs disposent déjà d'outils pour développer ou assurer la résilience des systèmes aquatiques et de pêche, tels que la gestion des prises et des zones lacustres. Parce que la gestion de la pêche interagit souvent avec de multiples parties prenantes, des stratégies d'adaptation impliquant les gestionnaires des pêches et d'autres partenaires, qui se concentrent sur l'utilisation des terres, les politiques et les systèmes humains, associés à la surveillance à long terme, sont nécessaires pour les systèmes souples. Nous montrons comment les agences et les organisations s'adaptent aux changements climatiques dans les lacs du Minnesota et de l'Ontario, ainsi qu'au niveau des ruisseaux du Montana. Nous présentons également la façon dont la Commission des poissons et de la faune de la Floride a créé une structure de gestion pour élaborer des stratégies d'adaptation. Ces exemples montrent comment les organisations et les agences peuvent faire face aux effets des changements climatiques sur les poissons et la pêche en créant une gestion et des systèmes écologiques souples.

KEY POINTS

- Adapting to climate change requires managing habitats, landscapes, and ecosystems to develop resilient fisheries.
- Resilient management is as important as resilient ecosystems.
- Managing for resilient systems requires collaboration between fisheries management and a wide range of partners focused on land use, policy, and human systems.
- Monitoring and managing for long-term change is needed.
- Uncertainty is certain, and decision makers can cope with the uncertainty.

INTRODUCTION

Fisheries managers have a long history of adapting management strategies to changing environmental and social conditions. Climate change is adding to the suite of uncertainties influencing fish populations and their response to management (Hansen et al. 2015). Managers have the ability to affect the ecological resilience, which is the capacity of a system to absorb or recover from disturbance while retaining its essential structure and function (Box 1; Holling 1973), and sustainability of fisheries resources by acknowledging uncertainty, employing decision-making strategies robust to uncertainty (e.g., scenario planning, Peterson et al. 2003; structured decision making, Irwin et al. 2011), and conducting the pre- and post-monitoring necessary to understand actual outcomes (Lempert et al. 2013). Some uncertainties bear strongly upon decisions, whereas others may be beyond managers' control. By understanding the difference, managers may be able to initiate management actions that reduce uncertainty (Irwin and Conroy 2013).

Although we have learned from documented fish responses to climate, to date these assessments are relatively limited (Lynch et al. this issue). Adaptation can be facilitated by forecasting future climate conditions, but such predictions are fraught with uncertainty (Lourenco et al. 2015), which is compounded by uncertainty in how natural resources respond to these changes (Wenger et al. 2013). Thus, decision makers are faced with a number of important questions in the context of climate change, such as, How will aquatic communities respond to changing water temperatures and flow regimes in five years? Ten years? A century from now? How reliable are downscaled climate models in predicting future conditions on the local to regional scale?

Our capacity to manage fisheries under a changing climate depends on reasonably accurate future predictions of ecological conditions but, more important, it depends on our ability to manage ecosystems in a way that buffers against some of these predicted changes by using a management structure

Box 1: Terms

Ecological resilience: The capacity of a system to absorb or recover from disturbance while retaining its essential structure and function (Holling 1973).

Resilient management: Management designed to adapt to rapidly changing ecological and social conditions.

Social resilience: The ability of human groups or communities to cope with external stresses and disturbances as a result of social, political, and environmental change (Adger 2000).

Adaptation: Minimizing the impact of climate change on ecological and social systems while exploiting beneficial opportunities (IPCC 2007).

General resilience: Does not focus on a specific attribute of a system or type of disturbance; focuses on maintaining core system attributes under a variety of unknown conditions and unforeseeable events (Carpenter et al. 2012).

Specified resilience: Answers the question “resilience of what, to what?” and is useful for minimizing the impact of well-defined potential stressors (Carpenter et al. 2012).

Adaptive management: An iterative process of using management decisions as experiments designed to learn about system responses and eventually reduce uncertainty.

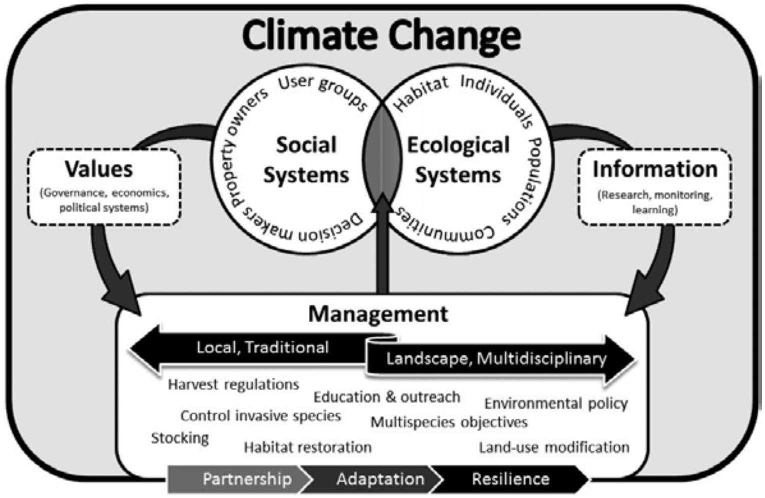


Figure 1. Conceptual models of how climate change may overlay upon development of management strategies, including how individual fish (Whitney et al., this issue), populations and communities (Lynch et al., this issue), and human behavior (Hunt et al., this issue) influence or respond to management decisions. Information is gathered from both management and social systems; thus, fisheries management is influenced by both empirical observations of aquatic ecosystems and value-based objectives of user groups, such that implemented policies are intended to buffer the interactions within socioecological systems. Adapting management for more resilient ecological and social systems will require increased partnerships and implementation across broader spatiotemporal scales.

designed to adapt to rapidly changing ecological and social systems (management resilience; Box 1) and environmental flexibility. Much like Aldo Leopold’s first rule of “intelligent tinkering” (make sure that you keep all the pieces; Leopold 1949), adapting to climate change means that fisheries and resource managers will need to consider how to maintain the key natural resource components required to sustain fisheries over the long term. Ecosystems that have already been degraded by anthropogenic activities will make climate adaptation even more challenging. Ensuring that managed systems operate within acceptable boundaries (Scheffer et al. 2015) to maintain certain characteristics or a diverse portfolio of fish populations in the face of climate change and other interacting stressors (MEA 2005; Haak and Williams 2012; Staudt et al. 2013) is challenging because interactions may be unforeseen, complex, and dynamic. Managers need to apply the best available science on how fish and habitats are responding to climate change (Lynch et al., this issue; Whitney et al., this issue), coupled with a strong focus on how resource users may respond to these actions (Hunt et al., this issue). In addition, fisheries managers will need to consider the context of both ecological and social systems (Figure 1). Adaptation strategies that incorporate partnerships across sociopolitical boundaries and other organizational structures (e.g., state/provincial agencies, federal agencies, nongovernmental organizations [NGOs], public interest groups) will be required for efficiency because of limited staffing, budgets, and expertise within any individual agency or organization.

The objectives of this article are to identify key components to the successful management of fisheries resources in a changing climate. We review adaptation strategies that agencies and organizations have developed to manage both ecological systems and their own administrative structures. We present case histories to demonstrate how agencies can adapt locally to manage systems in the face of climate change and discuss the importance of monitoring to detect change and adapt to new situations. Finally, we review challenges that organizations and agencies face in making decisions when uncertainty remains about how fish and fisheries will be affected by a changing climate.

MANAGING FOR ECOLOGICAL RESILIENCE

Fisheries management activities are unlikely to reverse the course of climate change; therefore, successful management will require adaptation. Because biological responses to climate hold uncertainty, adapting to climate change requires enacting strategies that are robust to unpredictable future conditions and their impacts and preparing for surprises and extreme events (Wilby et al. 2010). These strategies are varied but can include protection of watersheds (e.g., forest conservation easements) to minimize nutrients entering lakes, which reduces dissolved oxygen levels (Jacobson et al. 2013), to ensuring a diversity of population age classes through harvest regulations to buffer against year-class failure due to extreme events (Hansen et al. 2015). The capacity of a fisheries system to adapt to climate change will depend on its ecological resilience. Managing for ecological resilience requires a focus on processes and feedbacks that maintain or transform a system into a desirable state (Walker and Salt 2012). Acknowledging the interdependence of social and ecological systems is a critical component of managing for ecological resilience (Berkes and Folke 1998; Biggs et al. 2012; Walker and Salt 2012), and we call attention to managing for the resilience of both ecological and social systems for fisheries management (Figure 1).

Managing for resilient ecological systems requires protecting the mechanisms that maintain a desired structure or function, such as sustainable recreational fisheries, rather than managing for stability of a single population or yield (Holling and Meffe 1996; Chapin et al. 2010). Resilient ecosystems maintain critical functions under the novel, unknown conditions and extreme events associated with climate change (Folke et al. 2010). Multiple recommendations for resilient fisheries management strategies have been proposed (e.g., Biggs et al. 2012; FAO 2012; Pope et al. 2014), and these strategies may fall (in part) within the current purview of most inland fisheries management agencies. For example, managing freshwater systems to maintain a diversity of species and heterogeneous age structure can be achieved through harvest regulations and can increase a system's resilience to extreme events (Hansen et al. 2015). Non-harvest-based regulations can also improve resilience, including nutrient management and land-use regulations (e.g., Walsh and Fletcher 2015) and protected areas or refuges (Bengtsson et al. 2003). Applying heterogeneous management tools buffers against fallible management (Elmqvist et al. 2003); if one approach fails due to incomplete understanding or unanticipated events, other approaches may be more effective. In contrast, a focus on single-species management with highly specific goals (e.g., maximizing yield) may erode ecological resilience and increase the likelihood of collapse (Holling and Meffe 1996).

Managing for ecological resilience frequently requires confronting trade-offs, such as sacrificing fishery harvest or development opportunities in the present day, to ensure the long-term stability of the system as a whole (Holling 1996; Rist and Moen 2013). In the Minnesota Cisco *Coregonus artedi* example (Box 2), the persistence of Cisco and other native coldwater fish species in a warming climate requires protecting forests in the watersheds of important refuge lakes with conservation easements that forego near-term economic benefits of those lands being converted to agriculture or development (agricultural and developed land values are typically 50%–400% higher than forested lands). In other cases, trade-offs exist between managing for specified vs. general resilience (Folke et al. 2010; Walker and Salt 2012), which may be conflicting; that is, managing a fishery to withstand a specified disturbance may erode its capacity to withstand other types of unknown disturbances (Walker and Salt 2012). For example, managing for general resilience means maintaining some degree of separation among system components, such that harmful effects are not transmitted throughout the entire system (Carpenter et al. 2012). Specifically, decreasing connectivity among inland fish stocks may reduce the vulnerability of the entire system to a disease outbreak or exposure to invasive species. However, connectivity among populations or stocks is critical for the ecological resilience of a species to regional disturbances (Hilborn et al. 2003). Thus, managing for general resilience requires some level of suboptimal outcomes to specified events to maintain system functionality in an uncertain future (Rist and Moen 2013). Resilient management systems recognize such trade-offs and set priorities for both the short and long term in order to optimize management outcomes over the temporal scales most relevant to the resources they manage.

Ecological resilience may require reestablishing ecological processes that enable systems to respond to both human and environmental disturbances. We recognize that in most cases it is impossible to reset systems to early historical conditions prior to disturbance by increased human settlement several hundred years ago, but resilience requires maintaining processes and functions within the constraints set by current social and ecological systems. Partnerships can allow management actions that achieve ecological resilience where multiple objectives are balanced by a single resilience strategy. These activities often are beyond the exclusive purview of traditional fisheries management; thus, partnerships and collaborations will be necessary (Pierce et al. 2013; Box 3). For example, landowners, agencies, and NGOs worked together in the Blackfoot River, Montana, to change livestock grazing practices and plant riparian vegetation to promote stream shading and decrease water temperature. These practices have been effective at reducing summer water temperatures in tributary streams where threatened Bull Trout *Salvelinus confluentus* exist (Williams et al. 2015). This is a good example of a partnership restoring ecological function that will ultimately help the system buffer increasing temperatures that will result as climate warms.

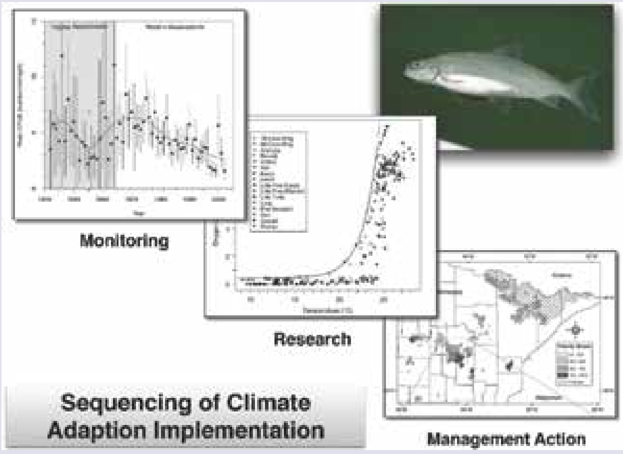
DEVELOPING RESILIENT MANAGEMENT SYSTEMS

In addition to managing for ecological resilience, adaptation to climate change will require that agencies and organizations build the capacity to act proactively, identify and respond to change, evaluate and refine actions, and manage social systems in addition to ecological systems; that is, fisheries management agencies must themselves be resilient (Arlinghaus et al. 2013). In this framework, human actions are viewed as part of a social–ecological system, whereby ecological and social dynamics are linked (Figure 1; Folke et al. 2010). One component of resilient systems is the capacity to learn about and adjust to changing conditions and drivers while also evaluating the outcome of past management actions (Folke et al. 2010; Pope et al. 2014). Monitoring (see next section) and adaptive management will allow fisheries management agencies to better identify the impacts of climate change and adjust to new environmental and social conditions (Allen et al. 2011; Hansen et al. 2015). Resilient management systems acknowledge and emphasize uncertainty, but uncertainty should not prevent a management action (Berkes and Folke 1998; Walker and Salt 2012); an absence of action is itself a management decision, which can potentially come at a high cost. Therefore, management entities should be structured to allow responses to unforeseen events to minimize and contain potential impacts (see Box 4). In some cases, management actions that anticipate possible changes may be warranted, whereby management strives to minimize projected impacts of climate change in high-priority locations. For example, planting trees in the riparian zones of streams where temperatures are projected to become unsuitable for high priority species can reduce the magnitude of temperature increases and maintain coldwater habitat longer than would be possible in the absence of such proactive strategies (e.g., Wilby et al. 2010; Box 3).

Social resilience also requires flexibility in stakeholder expectations and management objectives. That is, rather than a narrow definition of angler satisfaction hinging on the provision of a single species, social resilience may require an expansion of species preferences and the value of ecosystem services other than fishing (Berkes and Folke 1998; Hunt et al., this issue). Such a shift in focus from extraction of a single species to a

Box 2: Protecting Cisco Refuge Lakes in Minnesota Using a Landscape Approach

Fisheries scientists with the Minnesota Department of Natural Resources (MNDNR) analyzed long-term monitoring data, available starting in the 1940s, for an important forage fish Cisco *Coregonus artedi* and identified a declining trend in abundance (see figure). These trends led to a research program to identify causes of the declines and potential management solutions. Although Cisco are a coldwater fish sensitive to multiple ecological stressors including eutrophication, MNDNR researchers uncovered evidence that the decline was climate related (Jacobson et al. 2012). Cisco populations have apparently suffered from longer durations of stratification due to lake temperatures warming earlier and cooling down later that have allowed hypolimnetic oxygen levels to be depleted to critically low concentrations in some lakes.



Schematic diagram of sequence of steps used to develop and implement a climate adaptation strategy to protect Cisco in Minnesota lakes. The sequence including a monitoring program sufficiently long enough to detect a trend, research that directly described the thermal niche and predicted subsequent population responses, and then specific management actions that protected the resilience of important refuge lakes identified by the research.

A large Cisco summer kill during the unusually warm summer of 2006 allowed MNDNR scientists to accurately map the thermal niche of Cisco by measuring lethal temperature and oxygen concentrations in the field (Jacobson et al. 2008; see figure). Other deep, clear lakes in the region maintained excellent coldwater habitat conditions that were well below lethal levels. Based on that observation, a research collaboration with lake modeling colleagues at the University of Minnesota identified 176 lakes that were resilient (sufficiently deep and clear to provide suitable habitat for coldwater fish), even in a climate-warmed Minnesota (Fang et al. 2012).

Research results led to management action to protect Cisco habitat in these important refuge lakes. Protecting water quality in these coldwater fish refuge lakes has become the focus of a significant landscape conservation effort among a diverse coalition of partners that include local, state, and national resource and water quality agencies, and a number of nongovernmental organizations (NGOs; Jacobson et al. 2013). Extensive forests are being protected in the watersheds of these resilient systems that offer multiple benefits beyond coldwater fish habitat (e.g., protection of water quality and reduction of forest fragmentation) that allow funding from a number of nontraditional sources; i.e., forest protection and water quality initiatives; dnr.state.mn.us/tullibeelake.html; MNDNR 2016). Approximately US$4 million has been expended by local, state, and NGO partners working with landowners owners in prioritized Cisco refuge lake watersheds to develop private land forest protection plans and conservation easements (e.g., leechlakewatershed.org/index.cfm/pageid/14; Leech Lake Area Watershed Foundation 2016).

Box 3: The Blackfoot Challenge

The Blackfoot River is one of the most famous rivers in Montana and gained national recognition in the book and movie *A River Runs through It* (McLean 1976). By the late 1980s and the early 1990s, the people in the Blackfoot Valley recognized that they and the river system were facing mounting stressors. Mining, land-use change, and an expanding human population were colliding with the listing of grizzly bears and Bull Trout *Salvelinus confluentus* under the Endangered Species Act. Local residents banded together with state, federal, and local governments to build the “Blackfoot Challenge.” The challenge recognizes the unique values of the watershed to better address the management issues facing them (blackfootchallenge.org).

The challenge has spent the last two decades identifying the critical resource, economic, and social issues facing the watershed and built a blueprint for watershed restoration. Included in this plan is a recognition that climate change is occurring and that any plan will need to address emerging issues. Rather than develop specific climate-related actions, the goals of the plan are to develop resilient aquatic and terrestrial ecosystems. For example, one of the needs identified in the plan was to increase the resilience of stream temperatures to increasing air temperatures. This involved restoring functioning riparian areas in grazed lands by planting willows and riparian vegetation along stream banks to shade stream reaches and reduce local water temperature. Private landowners, state and federal managers, and nongovernmental groups like Trout Unlimited have worked together to implement these actions, in addition to other restoration activities such as channel reconstruction, improving fish passage, and restoration of stream flows. These actions have increased wild trout abundance in middle to upper watershed reaches, particularly in areas where partners have continued to minimize human activities such as riparian grazing (Pierce et al. 2013).

more holistic view of ecological services is no small challenge. Management agencies can foster social resilience through outreach and education designed to promote a shift in species preferences and broader participation in resource management (e.g., Biggs et al. 2012), but human behaviors are themselves resistant to change and thus may require an unforeseen crisis to adapt and even transform into a new set of values that promotes resilience (Gunderson 1999; Walker and Meyers 2004; Folke et al. 2010). Managing for resilient ecosystems, coupled with a management framework that provides administrative and social resilience, will allow agencies and organizations to better cope with a changing climate.

MONITORING AND MAKING DECISIONS

Fishery managers routinely rely on monitoring programs to assess spatial and temporal differences in resource status metrics, such as fish abundance or angler satisfaction. Monitoring is particularly important for tracking the impacts of climate change in freshwater systems, since projected impacts are uncertain (e.g., Jimenez Cisneros et al. 2014). However, empirical evidence demonstrating current effects of climate change on freshwater systems is beginning to emerge (Eby et al. 2014; Lynch et al., this issue). These outcomes can only be measured by monitoring programs designed to detect and track the primary signals expected from changes in climate. That is, to document change on the ground, there needs to be effort on the ground aimed at detecting change. Monitoring programs will likely continue to focus on detecting the emergence of expected changes, but they may increasingly need to adapt to new knowledge that will inevitably develop as potential individual, population, ecosystem, and social responses to climate changes become better understood. An effective climate change monitoring program can be a vehicle for both hypothesis development and testing. This is best done through a dual structure, consisting of (1) a core data collection program, designed to detect both expected trends (e.g., shifts in spawning phenology of benchmark species groups) and critical events and (2) a research program (linked to the core data collection program) that has an explicit mandate to develop and test new hypotheses around ecosystem responses to climate change, thus ensuring that the core program adapts and continues to generate knowledge regarding realized changes in climate and their impacts on freshwater ecosystems (e.g., Box 5).

Monitoring programs may produce information relevant to decisions, thereby allowing for evidence-based management (Wagner et al. 2013). These programs should monitor not just biophysical changes but also the attitudes and actions of the human users of inland aquatic systems (Hunt et al., this issue). The direct responses of stakeholders to changing climatic conditions and their responses to the ecosystem consequences of climate change will influence how best to manage for sustainable human use of these systems.

Monitoring can also produce the data needed to assess the consequences of management decisions, address uncertainty in the response, determine whether objectives were met, and possibly alter the management if the objectives were not met. Over time, monitoring programs can also distinguish among alternative hypotheses about system structure and function and improve understanding of how systems respond to management actions (Irwin et al. 2011; Irwin and Conroy 2013).

Comparable data on populations of managed species, spread across a broad climatic range, will help improve our understanding of how such populations respond to changes in climate. Monitoring at this broad spatial scale will likely cross jurisdictional boundaries, which further highlights the need to develop multi-agency collaboration to generate large, systematic landscape-level data sets. Data comparability will demand adoption of standard sampling protocols (e.g., Bonar et al. 2009) or completion of cross-calibration studies (Petersen and Paukert 2009) to generate comparable indices of system status from data collected using different methodologies.

Successful examples exist of freshwater monitoring programs capable of detecting the trends and abrupt shifts expected from systematic changes in climate. For instance, long-term monitoring identified declines of Cisco in northern Minnesota lakes caused by climate change, and this finding led to management actions to help restore this native species (see Box 2). In Ontario, monitoring has identified shifts in both the spawning dates and distributions of centrarchids, and thus led to changes in recreational fishing regulations (Figure 2).

CHALLENGES TO ADAPTATION STRATEGIES

The spatial and temporal scales of climate change will require rethinking some traditional management approaches. Many traditional fisheries management actions, such as stocking and angling regulations, are designed to influence single populations of species in local water bodies. Protecting and restoring the resilience necessary to sustain valuable fisheries in the face of climate warming will require expanding the scope of fisheries management beyond such approaches. Joining forces with other agencies and partners will be required to achieve the broad-scale conservation objectives necessary for managing

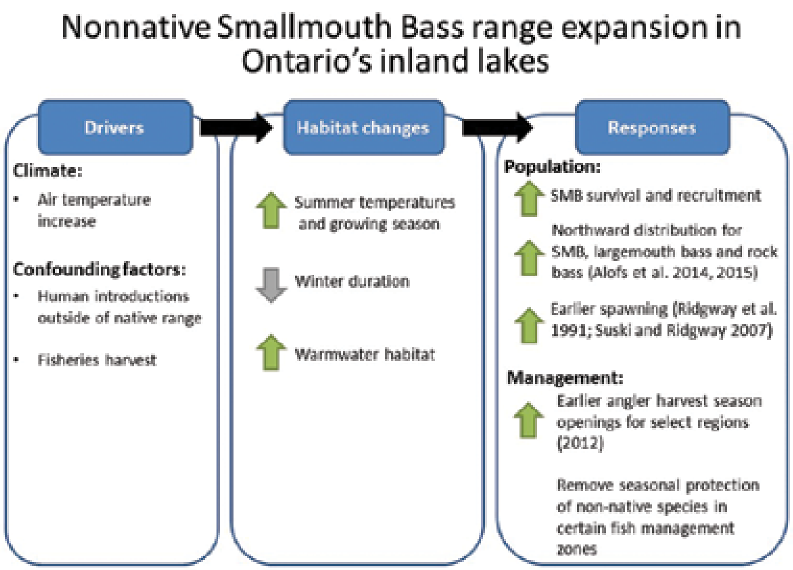


Figure 2. Documented consequences of the northward expansion and changes in spawning phenology of nonnative Smallmouth Bass (SMB) in Ontario's inland lakes facilitated by climate change and the adjustment in harvest regulations by agencies to adapt to these changes. Green arrows indicate an increase or earlier seasonal response; gray arrows indicate a decrease or later seasonal response.

Box 4: An Agency Adapts to a Changing Climate: The Florida Fish and Wildlife Commission Example

The State of Florida is largely a low-lying peninsula with approximately 1,900 km of coastline. Of the 4,368 species of plants and animals (invertebrate and vertebrate species) identified in the state in 2002, 269 of them were endemic (Stein 2002). Both species and habitats are under threats from a changing climate including impacts associated with rising sea levels, changes in precipitation patterns, increasing ocean acidity, and land-use conflicts arising from development and urbanization. The Florida Fish and Wildlife Conservation Commission (FWC) is charged with "managing fish and wildlife resources for their long-term well-being and the benefit of people" (myfwc.com/about/overview/programs/mission-benefits). Given this mission, the FWC is responding to threats related to a changing climate by developing resources, processes, and projects that can (1) anticipate changes to landscapes and seascapes, (2) identify species and systems that are most vulnerable, and (3) devise adaptation strategies that increase the adaptive capacity of the resources the FWC is mandated to conserve.

In 2008, the FWC developed a program designed to add internal capacity within the agency, thereby facilitating the development and incorporation of adaptation options within the agency's planning and operations. The structure of that program addresses priorities of a natural resources management agency focusing on species and habitat conservation and management, invasive species control, and providing recreational opportunities for stakeholders. More specifically, the FWC created workgroups focused on climate adaptation, research and monitoring, communications and outreach, and planning and policy. The work groups are overseen by a steering committee of senior managers and administrators (see figure). Given the focus on internal capacity building, a nine-month internal "climate change certification course" was launched. This course consisted of monthly lectures by nationally renowned climate scientists and practitioners. The course included lectures and readings focused on climate science, climate change effects, vulnerability analyses, adaptation development, communications, and policy; a follow-up course addressed more Florida-specific issues. These courses have served as the basis for the National Conservation Training Center's "Climate Academy" and the California Department of Fish and Wildlife's "Climate College."

The Florida Fish and Wildlife Conservation Commission (FWC) Climate Program's structure including the linkages to operational plans and actions. The Adaptation and Research and Monitoring workgroups are composed of subgroups of both managers and scientists who work together to develop adaptation strategies to incorporate into the agency-wide plans (e.g., Agency Strategic Plan). Operational plans include for example the State Wildlife Action Plan, the Imperiled Species Management plans, and Wildlife Management Area plans. Some examples of actions may include changes in prescribed burning practices to account for changing climatology, adjusting water-release schedules from impoundments to ensure suitable estuarine salinity for aquatic "species of greatest conservation need," and changes in fishing seasons to preserve fish reproductive output.

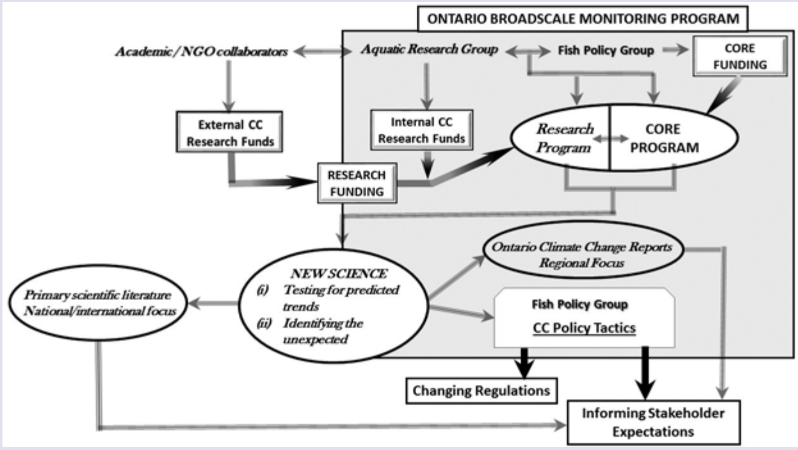
To build on these activities, the work groups are developing an adaptation guide to provide baseline information that will support incorporating climate change into planning and management processes and actions. The guide will present the current state of the science and predicted changes in the state, the ecological consequences of those changes, and guidance on possible adaptation strategies that could be incorporated into management actions under the emerging threats.

The FWC has also funded a number of projects through existing funding mechanisms including the State Wildlife Grants Program to help understand plausible future impacts. These projects focused on assessing the vulnerabilities of Florida's species and natural communities, developing information that will influence and guide inclusion of climate change into planning processes, and implementing and assessing adaptation strategies. In some cases, projects focused on possible social and economic futures that could guide planning. The projects are designed to build upon each other so that ultimately a comprehensive roadmap for conservation under a changing climate can be developed. In some cases, on-the-ground projects have tested concepts that have emerged from this process including bank stabilization, developing living shorelines, and removing barriers to connectivity.

To date, several FWC planning processes have integrated climate impacts, including a dedicated chapter in the 2015 revised version of the State Wildlife Action Plan, Imperiled Species Management plans and associated Integrated Conservation Strategy, and Wildlife Management Area plans as they cycle through the scheduled revision process. "Climate-smart" approaches have been introduced to managers of two of the FWC's wildlife management areas as a pilot, and the feedback is informing a more comprehensive project that will address the management plans of several of the state's wildlife management areas and U.S. Fish and Wildlife Service refuges under threats from rising seas and land use change. All of the activities of the FWC climate change program are designed to build internal capacity, develop partnerships, and reduce uncertainty. Importantly, the FWC climate activities are designed to develop a more adaptive agency, increase the resilience of the resources under their stewardship in the face of emerging threats, and instill a culture of considering a changing climate in the agency's plans.

Box 5: The Broadscale Monitoring Program by the Ontario Ministry of Natural Resources and Forestry

The Ontario Ministry of Natural Resources and Forestry Broadscale Monitoring Program (2008–present) is an example of a resilient monitoring program that is capable of detecting the trends and abrupt shifts expected from systematic changes in climate (see figure). Its dual structure of research and core components (see figure) ensures that (1) the research program develops new knowledge about the likely impacts of climate change on Ontario's freshwater resources and (2) the core monitoring program efficiently incorporates that new knowledge in order to maintain its ability to detect the realized impacts of climate change. The program is designed to operate over successive five-year cycles. In each cycle, a representative sample of approximately 700 lakes is randomly selected from the approximately 11,000 lakes greater than 500 ha in Ontario. These lakes are surveyed within a two-month window using identical survey protocols. Data from the core survey program characterize: (1) lake water chemistry and temperature, (2) zooplankton abundance, (3) fish community composition, (4) relative abundance and life history characteristics of sport fishes (e.g., Lake Trout *Salvelinus namaycush* and Walleye *Sander vitreus*), and (5) fishing intensity and other indices of human use. Data from the core program and related Ontario Ministry of Natural Resources and Forestry surveys have been used to detect trends toward earlier spawning dates in Ontario centrarchid populations and to identify northward shifts in centrarchid zoogeographic distributions across the province (Alofs et al. 2014; Alofs and Jackson 2015). These findings have led to changes in recreational fishing seasons in different regions of the province (Figure 2). Results from the research program have extended earlier work (e.g., VanderZanden et al. 1999; Venturelli et al. 2010) to show how changes in climate may affect sustainable harvests of Walleye and Lake Trout (Lester et al. 2014; Tunney et al. 2014).



Schematic diagram of the management and outputs of the Ontario Broadscale Monitoring Program. Arrows indicate connections between groups involved in running the program, and generating and using its products. Relevance of its data products to climate change (CC) is highlighted. Compound arrows are science information pathways; gradient arrows are funding pathways; solid black arrows are policy and stakeholder pathways.

resilience in aquatic systems. For example, protecting coldwater fishes that are particularly susceptible to warming temperatures requires coordinated efforts from local, regional, national, and sometimes international management groups. These efforts will also require coordinated efforts from local communities and private landowners, tribal entities, and state/provincial and federal governments (see Box 3). Though there are several examples of successful partnerships to address fisheries issues, the scale of coordination, the recognition of the roles of the various parties, and the development of meaningful actions can be a challenging process. Frameworks that explicitly incorporate climate adaptation into broad-scale conservation will be valuable (Schmitz et al. 2015). In addition, governmental policies and decisions often work at different purposes and administrative levels in the development and implementation of conservation goals. Negotiating the balance between resource sustainability and the economic and social consequences of implemented actions will require difficult decisions and in some cases lost opportunities. Government actions coordinated across all scales are necessary and will require us to take the "long" view for resource sustainability.

Adequate funding and valuation by the public for fisheries conservation and management has always been a challenge, and adding climate change to the myriad of issues facing agencies and organizations will make funding prioritization even more challenging. New partnerships among government, private, and nongovernmental organizations will be needed to expand the resources available to address climate-induced challenges. In some cases, these partnerships have already been formed and have recognized the need to address climate change in current management (see Box 3). Funding developed from multiple sources, including the private sector, will be needed to meet management needs moving forward.

One challenge is that many conservation partnerships have been developed to conserve and manage species of concern or charismatic species. We typically have more information on the life history and basic biology of these charismatic or economically important species than the thousands of other species that exist on the landscape. Though cool/coldwater game fishes have received much of the attention, other species may provide important information on thermal tolerances and resistance to changing temperatures and how rapidly organisms can respond and adapt to changing conditions (Whitney et al., this issue). In a recent assessment of Missouri stream fishes' vulnerability to climate and land use change, 25% of the species could not be assessed because of limited information on thermal and flow tolerances of those species (Sievert et al. 2016). In addition, nonnative species are sometimes habitat generalists that are more tolerant of changing environmental conditions and thus represent a threat to aquatic systems where desired native recreational, commercial, and subsistence fisheries may exist (e.g., Common Carp *Cyprinus carpio*). Understanding how climate affects these relationships will be important to sustain these opportunities or, in some cases, realize where we need to reprioritize our management actions.

CONCLUSIONS

Decision makers can cope with climate change and its effects on fish and fisheries by developing resilient ecological and management systems and monitoring the ecological systems to detect changes. Our knowledge of how climate change affects individual fish, populations, and communities is certainly incomplete but is growing (Lynch et al., this issue; Whitney et al., this issue). Managers may consider prioritizing monitoring for the production and use of information to enable defensible, evidence-based decision making. Currently, some on-the-ground monitoring programs are producing decision-relevant information, and agencies are adapting in response to changing socioecological influences (Hunt et al., this issue). System monitoring can help increase the quality and quantity of information available to policy makers (e.g., question-driven monitoring) and also help assess whether outcomes match expectations (e.g., metric-driven monitoring). Furthermore, we believe that managing for resilience will require expanding the definition of fisheries management beyond traditional boundaries. Such efforts will require broad-reaching partnerships and will be critical for adaptation on a scale that produces meaningful results.

Climate change and its associated effects will be one of the grand challenges facing fisheries management in the future. We suggest that managers and their partners are making substantial strides in developing resilient systems. Continued adaptation and decision making based on long-term monitoring will help us learn more about the effects of climate change on fish and fisheries, aquatic communities, and the users of these resources. This growing knowledge base will allow managers to mobilize the best available science in making the decisions needed to sustain, enhance, and restore fish populations.

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