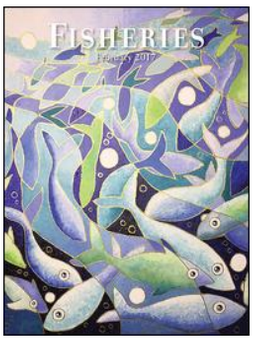

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FEATURE

Grand Challenges in the Management and Conservation of North American Inland Fishes and Fisheries

Abigail J. Lynch | U.S. Geological Survey National Climate Change and Wildlife Science Center, 12201 Sunrise Valley Drive, MS-516, Reston, VA 20192. E-mail: ajlynch@usgs.gov

Steven J. Cooke | Fish Ecology and Conservation Physiology Laboratory, Department of Biology and Institute of Environmental Sciences, Carleton University, Ottawa, ON, Canada

T. Douglas Beard, Jr. | U.S. Geological Survey National Climate Change and Wildlife Science Center, Reston, VA

Yu-Chun Kao | Center for Systems Integration and Sustainability, Department of Fisheries and Wildlife, Michigan State University, East Lansing, MI

Kai Lorenzen | Fisheries and Aquatic Sciences, School of Forest Resources and Conservation, University of Florida, Gainesville, FL

Andrew M. Song | Department of Natural Resource Sciences, McGill University, Ste-Anne-de-Bellevue, QC, Canada

Micheal S. Allen | Fisheries and Aquatic Sciences, School of Forest Resources and Conservation, University of Florida, Gainesville, FL

Zeenatul Basher | Center for Systems Integration and Sustainability, Department of Fisheries and Wildlife, Michigan State University, East Lansing, MI

David B. Bunnell | U.S. Geological Survey, Great Lakes Science Center, Ann Arbor, MI

Edward V. Camp | Fisheries and Aquatic Sciences, School of Forest Resources and Conservation, University of Florida, Gainesville, FL

Ian G. Cowx | Hull University, International Fisheries Institute, Hull, UK

Jonathan A. Freedman | Fisheries and Aquatic Sciences, School of Forest Resources and Conservation, University of Florida, Gainesville, FL

Vivian M. Nguyen | Fish Ecology and Conservation Physiology Laboratory, Department of Biology and Institute of Environmental Sciences, Carleton University, Ottawa, ON, Canada

Joel K. Nohner | Center for Systems Integration and Sustainability, Department of Fisheries and Wildlife, Michigan State University, East Lansing, MI

Mark W. Rogers | U.S. Geological Survey, Great Lakes Science Center, Ann Arbor, MI

Zachary A. Siders | Fisheries and Aquatic Sciences, School of Forest Resources and Conservation, University of Florida, Gainesville, FL

William W. Taylor and So-Jung Youn | Center for Systems Integration and Sustainability, Department of Fisheries and Wildlife, Michigan State University, East Lansing, MI

Even with long-standing management and extensive science support, North American inland fish and fisheries still face many conservation and management challenges. We used a grand challenges approach to identify critical roadblocks that if removed would help solve important problems in the management and long-term conservation of North American inland fish and fisheries. We identified seven grand challenges within three themes (valuation, governance, and externalities) and 34 research needs and management actions. The major themes identified are to (1) raise awareness of diverse values associated with inland fish and fisheries, (2) govern inland fish and fisheries to satisfy multiple use and conservation objectives, and (3) ensure productive inland fisheries given nonfishing sector externalities. Addressing these grand challenges will help the broader community understand the diverse values of inland fish and fisheries, promote open forums for engagement of diverse stakeholders in fisheries management, and better integrate the inland fish sector into the greater water and land use policy process.

INTRODUCTION

The United States and Canada (herein referred to as North America for sake of brevity and given similarity in resource management philosophy, though we acknowledge the geographic inaccuracy of excluding Mexico) are home to a range of inland ecosystems supporting more than 1,200 fish species (Burkhead 2012), used by diverse fisheries (e.g., indigenous, commercial, and recreational), and valued by an even more diverse set of stakeholders (Cooke and Murchie 2015). We use the general term "fish" in colloquial reference, "inland" to label land-locked waters, and "fisheries" as the capture of populations and communities of fished or fishable animals for food, income, or recreation. Despite significant scientific capacity, long-standing governance structures (many >50 years), and relatively reasonable funding for fisheries management and conservation compared with other regions, inland fish and those responsible for their management and conservation still face many challenges in North America.

Inland fish and their associated ecosystems face diverse threats such as climate change, habitat alteration and fragmentation, water extraction, and pollution (Dudgeon et al. 2006; Carpenter et al. 2011). These threats are often more important than effects of exploitation, although fishing can still be substantial in some cases (Miller et al. 1989; Post et al. 2002; Bunnell et al. 2014). Social, economic, and cultural issues in inland fisheries management arise as consequences of impacts that originate outside the fisheries sector (Malvestuto and Hudgins 1996), but such issues may also arise internally where the specific social–ecological factors are not accounted for in management (e.g., fishing regulations designed with insufficient understanding of motivations held by fishers; Scrogin et al. 2004) or where fundamental motivations conflict between stakeholders (e.g., recreational and commercial fishers or recreational fishers and animal rights activists).

Inland fisheries managers have been successful in addressing many threats and challenges through regulations such as those that restrict exploitation, enhance habitat conservation and restoration measures, and facilitate control of invasive species (Arlinghaus et al. 2016). Though some threats have abated (e.g., industrial pollution is no longer the threat it once presented), new challenges have emerged (e.g., climate change) and existing challenges have magnified in certain regions (e.g., water allocation conflicts in arid regions of North America). Most challenges have both biological and human dimensions components that are inherently linked (Arlinghaus et al. 2013) and need to be considered, and addressing them requires engagement with other sectors and stakeholders. Though fishery professionals have been largely trained in the biological dimensions, new fisheries managers quickly learn that human dimensions components often quickly eclipse the complexity of the biological ones. The complexity of working at the interface of people, fish, and habitat is the major challenge to inland fisheries research, management, and policy. The purpose of our article is to highlight these challenges, which we have divided into three themes (valuation, governance, and externalities), and outline research and management needs for their resolution.

GRAND CHALLENGES EXERCISE

Over the past decade, there have been growing calls to use expert knowledge and gap analysis to identify grand challenges related to various social justice, health, and environmental problems (Schwenk et al. 2009). Put simply, a grand challenge is a specific, critical roadblock that if removed would help solve an important problem. The grand challenges approach is a strategic platform for identifying barriers that impede the ability of society to address pressing problems. The process assembles a small group of disciplinary experts to compile a short list of grand challenges through facilitated group discussions. One of the earliest and most high-profile grand challenges exercises focused on global health, which led to 23 specific challenges and subsequently targeted philanthropic investment by the Bill and Melinda Gates Foundation and other organizations (Varmus et al. 2003). Since then, grand challenges exercises have been conducted for various disciplines (e.g., organismal biology: Schwenk et al. 2009; movement ecology: Bowlin et al. 2010) and issues (e.g., environmental sustainability: Reid et al. 2010; rangeland management: Bestelmeyer and Briske 2012) in order to help to direct research activity and identify targeted areas for funding or management action.

Our grand challenges exercise focused on management and conservation of North American inland fish and fisheries. In Florida in April 2015, we assembled a diverse group of inland fisheries professionals (the authors) representing a range of perspectives on the issues. Many of the authors have not only conducted research on inland fish and fisheries but have been engaged in related management and policy issues. The rationale for the regional focus was that, on a global scale, the management capacity and objectives, governance structures, and patterns of exploitation (e.g., relative role of different fishing sectors) for inland fish and fisheries vary widely (see Welcomme et al. 2010), such that some level of geographic scoping was needed to identify meaningful grand challenges. Across North America, fisheries management is (relatively) well financed and fundamentally driven by the public trust doctrine (as opposed to private-rights models in other regions). Through a facilitated group discussion, we identified a large list of potential grand challenges targeted broadly toward resource managers, researchers, fisheries practitioners, politicians, and other relevant stakeholders. We collapsed similar suggestions and hierarchically grouped the remaining grand challenges into themes (Figure 1) with associated needs (Table 1) and briefly describe them below.

Theme A. Raise Awareness of the Diverse Values of Inland Fish

North American inland fish and fisheries embody diverse economic, cultural, nutritional, and ecological values (Malvestuto and Hudgins 1996). Capturing these values in a manner that renders them comparable for decision making remains difficult;

the diverse values require a common currency. Expenditures are a well-articulated metric because expenses associated with recreational and commercial fisheries can be most readily quantified in monetary terms but they represent a minimum absolute value of monetized benefits of a fishery. For example, expenditures are estimated at just under US$3 billion for Great Lakes recreational fisheries but the economic output (total multiplier effect) of these fisheries is estimated to be worth more than US $7 billion (Southwick Associates 2013). Cultural values, on the other hand, are often nonmaterial and intangible; they are particularly important to aboriginal groups who hold that inland fish and fisheries contribute to sense of place and heritage and even have spiritual value (Chan et al. 2012a, 2012b). Similarly, recreational fishing also confers value by contributing to self-identity, social belonging, and a feeling of connection with nature, as well as psychological well-being, stress release and health benefits, and mental satisfaction (Toth and Brown 1997; Kearney 2002). Inland fish are also nutritionally valuable to those who engage in subsistence fishing or otherwise consume fish as a healthy food source. Through the consumption of species such as Rainbow Trout *Oncorhynchus mykiss*, catfish (*Ictaluridae*), and Lake Whitefish *Coregonus clupeaformis*, North Americans, regionally, have an accessible source of animal protein and micronutrients, including omega-3 fatty acids and vitamin D (Youn et al. 2014). Additionally, inland fish are an essential component of aquatic ecosystems, playing a critical part of biodiversity and the integrity of aquatic habitats (e.g., regulation of food web dynamics, recycling of nutrients, container of ecological memory, control of hazardous diseases, and energy transport: Holmlund and Hammer 1999; Lynch et al. 2016). Within the theme of valuation, we identified two specific grand challenges (GCs):

GC A.1. Implement Evaluation Methods That Accurately and Reliably Estimate Value and Enable Comparison among Multiple Uses

Though traditional valuation methods exist (e.g., cost–benefit analysis, ecosystem services valuation), their application to inland fisheries management is a recognized need. These tools have, in many cases, not been applied cogently to inland fisheries. The issue is related to the number of different kinds of values and services provided by inland fish and fisheries, all of which need to be properly accounted for, but these values can be conflicting and even somewhat incomparable in nature (Martinez-Alier et al. 1998; Trainor 2006; Kooiman and Jentoft 2009; Cowx and Portocarrero Aya 2011; Chan et al. 2012b). Economic values have attracted much research and policy attention in part due to the ease of integration into standard decision-making models such as cost–benefit analysis. Yet, even as valuation exercises become more widely available (e.g., Fenichel et al. 2016), application of the theory to inland fisheries management is not common; for instance, the values of inland fisheries management actions (e.g., fisheries enhancements) and ecosystem services (e.g., clean water contributions to human health) are not often quantified.

Several methods have been developed to facilitate the valuation of the nonmarket, nonmaterial, intangible, transformative, or sacred values of inland fish that do not conform to the assumptions of economic valuation. These methods include optimal yield (Malvestuto and Hudgins 1996), travel cost (Shrestha et al. 2002), contingent valuation and preference surveys (Willis and Garrod 1999), paired comparisons (Song and Chuenpagdee 2013), and narrative methods (Satterfield 2001). However, given their disparate methodological assumptions that cater to specific application contexts, no one method is universally applicable across each of the different inland fisheries sectors. In order to link these sectors holistically, environmental economists are promoting the use of a common currency that would be developed through the use of inclusive valuation frameworks, rather than solely relying on the aggregation of separately measured individual indicators (de Groot et al. 2002; Chan et al. 2012a). We submit that developing and applying extant frameworks that include the likely heterogeneous norms and valuation of stakeholders will be the most comprehensive approach for quantitatively describing the holistic values of inland fish and fisheries, and commitment to engagement is necessary for it to occur.

GC A.2. Elevate the Political Priority of Societal Contributions

The lack of a comprehensive valuation framework can engender a weak or skewed understanding about the full range of inland fishery benefits, which may influence public policy and stakeholder discourse (de Groot et al. 2002; Beard et al. 2011; Cooke et al. 2013). We hold that by identifying their full value, inland fisheries would be less likely to be marginalized in comparison to competing sectors for inland water resources (e.g., agriculture, hydropower, flood control, and urban development), which currently are able to present more robust estimates of worth.

Developing strategies for enhancing science–policy communication to inform wider audiences, including nongovernmental organizations and decision makers at various levels of government, of the societal contributions of inland fish and fisheries may enable better integration of fisheries stakeholder values and perspectives in larger policy discussions. Environmental education initiatives could help provide greater involvement of the public, whose informed voices can subsequently be championed by politicians. Some of the possible interventions could include making public education a mandatory component of scientific grants (e.g., now required in some National Science Foundation grants), providing built-in opportunities for stakeholders to provide input in decision-making processes (e.g., sitting on a regional management committee), public outreach, generating media interest, and actively engaging professional communicators (see Cooke et al. [2013] for more detailed descriptions). A study of stakeholder perspectives to understand people's motivations, beliefs, and other emotional investments in a given fishery, and its supply chain would also form an important aspect of ongoing research needs.

Theme B. Govern Inland Fish and Fisheries to Satisfy Multiple Use and Conservation Objectives

To balance multiple use and conservation objectives (e.g., recreational, commercial, and subsistence), North American inland fisheries governance will require and effectively (and cost efficiently) engagement with a very wide range of stakeholders. Governance systems can be designed—and adequately funded—to cover the entire area over which a fishery interacts (including external sectors on nested spatial and temporal scales) and support broad objectives and all legitimate water uses. Effective engagement of stakeholders through codevelopment of governance systems is crucial, particularly because balancing management objectives usually means compromise and that participation in the public process makes stakeholders more vested in the outcomes. A few notable examples that foster such multiagency and cross-sectoral governance structures include the Lower Mississippi River Conservation Committee and the Great Lakes Fishery Commission. Novel funding mechanisms may be necessary to maintain current activities and advance new initiatives within inland fisheries management. Within the theme of governance, we identified two specific grand challenges:

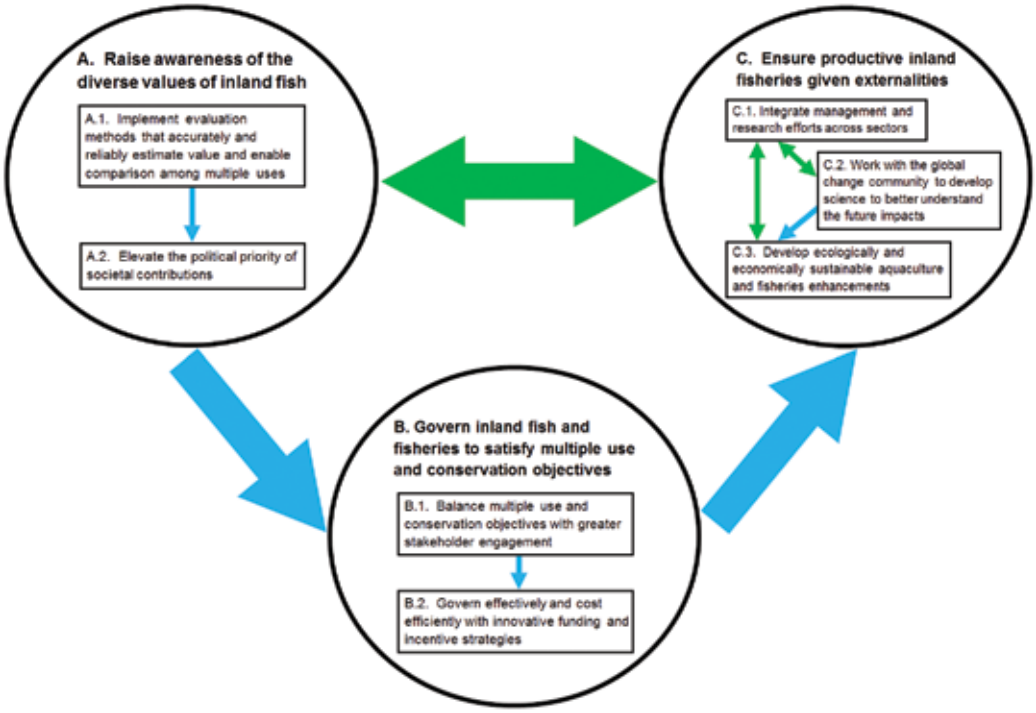

Figure 1. Grand challenges in the management and conservation of inland fish and fisheries of Canada and the United States, organized by theme. Blue arrows indicate that action on one grand challenge theme will drive progress on another; green arrows indicate that action to address the grand challenge themes reinforce each other.

GC B.1. Balance Multiple Use and Conservation Objectives

Many conflicts arise in governance of North American inland fisheries because use or conservation objectives of some stakeholders are overlooked or deliberately ignored and the consequences of alternative management actions are not considered. For example, because of the current funding models, fish and wildlife agencies often have ways to engage directly with their license holders (e.g., contact information is often required when purchasing a license), but other users who may be exempt from license requirements (e.g., many states and provinces offer free licenses to anglers over a certain age, active military, and disabled citizens) nonetheless account for a substantial share of resource use. Similarly, nonfishers (e.g., leisure boaters, nonfishing conservationists) are generally excluded from management discussions because they are not tracked as fisheries stakeholders (note that this is not always the case; for example, a portion of U.S. Sport Fish Restoration funding is directed at boaters). Conflicts are further generated when different stakeholders support opposing uses and objectives for the same resource; for example, competing allocation of funding within multiple fisheries sectors or between the fisheries sector and other competing sectors for inland water resources, procedural disagreements about decision making, and fundamental differences in core values (e.g., between animal rights advocates and anglers).

Systematically identifying multiple-use and conservation objectives through community-based approaches and communicating with the full subset of stakeholders will help avoid mismatch in spatial and temporal scales between needs of inland fisheries stakeholders and governance strategies, particularly with current funding models. Fisheries performance indicators, developed primarily for marine commercial fisheries (Anderson et al. 2015), can be modified to reflect multiple use and conservation objectives for inland fisheries with major recreational or subsistence-oriented components and external drivers (e.g., management measures to maintain sustainable recreational fisheries *and* protection for endangered species). Likewise, the use of marine spatial planning could be more widely applied in inland systems to facilitate management at a watershed scale, separate conflicting uses, and enhance place-based management and stewardship (Lorenzen et al. 2010; Cooke et al. 2014). Engaging a diversity of stakeholders effectively in this process is often difficult for fisheries professionals because they are predominantly recruited from biological science backgrounds and may lack training and experience in communication, facilitation, and stakeholder engagement, as well as knowledge of other sectors impacting inland systems and an appreciation for the public process. Relevant education and training, including opportunities for continued development of community-building and negotiation skills for fisheries professionals, can be provided in conjunction with active encouragement for stakeholder engagement and regular contact with professional communicators. Because inland fisheries governance in North America is principally at the provincial or state level, community-based initiatives are often appropriate to promote stewardship, particularly for local-scale fisheries.

GC B.2. Govern Effectively and Cost Efficiently with Greater Stakeholder Engagement

Almost all inland fisheries resources in Canada and the United States are held in public trust, with the states and provinces as trustee and primary steward. Public trust emphasizes access to these resources for all and is a key role for agencies conserving fisheries resources (Frank 2011). The public trust doctrine and its implementation have been broadly successful in achieving these goals (Baer 1987). However, the doctrine can also lower incentives for environmental stewardship or resource enhancement vis-à-vis private use rights models (such as commonly found in Europe; see Scott 1989) and can pose barriers to the effective regulation of fishing effort because access cannot easily be restricted

Table 1. Grand challenges in the management and conservation of inland fish and fisheries of Canada and the United States.

Themes	Grand challenges	Research needs and actions for management agencies
A. Raise awareness of the diverse values of inland fish	A.1. Implement evaluation methods that accurately and reliably estimate value and enable comparison among multiple uses	A.1.1. Investigate each different inland fisheries sector (subsistence, commercial, and recreational) and evaluate its social and economic value across landscape scales
		A.1.2. Quantify fishery contribution to human health, food, and livelihoods
		A.1.3. Develop inclusive valuation frameworks for assessing nonmeasurable cultural, social, and religious values
		A.1.4. Develop ways to quantify the values of ecosystem services, habitat protection, habitat restoration, compensation strategies (e.g., habitat banking), and ecosystem-based management
		A.1.5. Investigate costs and benefits of fisheries enhancements
	A.2. Elevate the political priority of societal contributions	A.2.1. Develop an understanding of societal investments in fisheries by studying stakeholder attitudes and beliefs
		A.2.2. Create effective communication strategies to inform decision makers of the diverse values of inland fisheries
		A.2.3. Engage the public in education and outreach activities to increase recognition of relationships among ecosystem integrity, fisheries production, and food security
B. Govern inland fish and fisheries to satisfy multiple use and conservation objectives	B.1. Balance multiple use and conservation objectives with greater stakeholder engagement	B.1.1. Create community-based strategies to promote economic, cultural, and societal values of fishery resources
		B.1.2. Systematically identify majority and minority use and conservation objectives of diverse stakeholders to avoid mismatch in spatial and temporal scales among stakeholders, research, governance, and fishery resources
		B.1.3. Develop and use fisheries performance indicators that reflect multiple-use and conservation objectives
		B.1.4. Build tools to assess fisheries condition and facilitate fisheries management at the watershed scale to ensure spatial match of management practices
		B.1.5. Develop and communicate analyses across sectors to assess consequences of alternative management actions
		B.1.6. Provide continued communication training opportunities to fishery managers to manage conflicts among diverse interests of stakeholders
		B.1.7. Engage stakeholders in balancing and prioritizing objectives and setting targets as well as developing quantitative fishery and social–ecological models
	B.2. Govern effectively and cost efficiently with innovative funding and incentive strategies	B.2.1. Seek to acquire funding that reflects the balance of objectives and associated activities and costs
		B.2.2. Develop governance structures and processes that provide incentives for stakeholder involvement, regulation compliance, and investment in environmental stewardship
		B.2.3. Examine principles and implementation of the public trust doctrine with respect to balancing access and incentives for proactive management (which may require more restricted access)
		B.2.3. Manage stakeholder conflict to allow constructive problem solving and effective use of science
		B.2.4. Obtain and communicate scientific evidence to support decision making, using established and innovative approaches (targeted studies, systematic reviews, adaptive management, traditional ecological knowledge, and citizen science)
C. Ensure productive inland fisheries given externalities	C.1. Integrate management and research efforts across sectors	C.1.1. Establish communication platforms for exchanging cross-sectoral perspectives on ecosystem management goals, needs, and priorities across sectors
		C.1.2. Identify conflicting management goals, evaluate trade-offs among fisheries and other ecosystem services, and promote these synergies across sectors
		C.1.3. Prevent and mitigate the spread of fish diseases and invasive species and adapt systems where they have already been established
		C.1.4. Adopt a precautionary approach to new pollutants and develop monitoring programs for early detection
		C.1.5. Establish cross-sectoral expert directory that makes information on personnel with specialized knowledge and skills accessible
		C.1.6. Develop a standardized and centralized data archiving and sharing framework across sectors to promote future collaboration
	C.2. Work with the global change community to develop science to better understand the future impacts	C.2.1. Assess the distribution and condition of future fish habitats under climate change
		C.2.2. Assess fish responses to climate change including range shifts, phenology, alternative life histories, and decreased production
		C.2.3. Study changes in nutrient dynamics and their impact on fishes and human health
		C.2.4. Develop quantitative and predictive fisheries system modeling tools that explicitly account for effects of habitat (e.g., structural, water quality) and its alteration
		C.2.5. Assess ways in which global change will influence fisheries management needs and approaches
	C.3. Develop ecologically and economically sustainable aquaculture and fisheries enhancements	C.3.1. Develop quantitative modeling tools for predicting ecological and economic impacts of increased aquaculture and fisheries enhancement
		C.3.2. Assess impacts of aquaculture and fisheries enhancement, such as escapement, disease, competition for food resources, and effluent on wild fish
		C.3.3. Develop tools to inform site choice and best management practices for aquaculture and fisheries enhancement

Top: *Valuation:* The value of North American inland fisheries extends beyond monetary terms (photo credit: U.S. Fish and Wildlife Service). Center: *Governance:* Decision makers can consider multiple uses and management objectives for inland fisheries (photo credit: Great Lakes Fishery Commission).Bottom: *Externalities:* Inland fisheries are part of a complex system including many other important water users (photo credit: Phil Bettoli).

(e.g., historical collapses of recreational fisheries; though seasonal closures are now often used to limit access). Principles for and implementation of the public trust doctrine can be appropriately evaluated for their effectiveness in promoting sustainable fisheries. Governance structures and processes, including regulatory compliance, voluntary conservation measures, and stakeholder participation in decision making, could be designed to incentivize environmental stewardship (e.g., better fishing opportunities or a tax break for participating in certain sustainable initiatives).

North American inland fisheries management agencies collectively seek to fulfill a very broad mission, from the promotion and utilization of fisheries resources (arguably their core mandate) on the one hand to the protection and restoration of threatened and endangered species on the other. Deciding when, where, and how to allocate resources is difficult. Funding of agencies is often heavily dependent on license fees and on excise taxes levied on the sale of outdoor gear. However, protection and restoration-oriented efforts are also legally mandated (e.g., the Endangered Species Act in the United States and the Species at Risk Act [SARA] in Canada), or otherwise expected from the nonfishing, as well as fishing, public. Sportfishing license fees are often tagged for recreational species, and other funding lines are dedicated to threated and endangered species (e.g., Species Recovery Grants to States and Provinces, Fish Habitat Partnerships, Bring Back the Natives program, Threatened and Endangered Species Recovery Fund, and SARA Recovery Strategy and Action Planning process). These divergent mandates and funding sources highlight the potential conflict of interest among stakeholders and even within management agencies. Effective use (and communication) of science to support decision making can minimize stakeholder conflict. Current funding mechanisms are no longer sufficient (e.g., license revenues are declining; Ross and Loomis 1999) and may present an opportunity to consider innovative funding processes. Though no solution will be simple, new tax measures could be considered for entities that contribute to threatened and endangered species or state and provincial appropriations could be treated as base funding rather than stakeholder driven. With these potential options, it is important to recognize that pooling funds could result in inadequate funding of previously identified priorities that do not fall within new pooled categories.

Theme C. Ensure Productive Inland Fisheries Given Externalities

North American freshwater ecosystems provide a range of services beyond fisheries, including, for example, drinking water, irrigation for agriculture, flood control, and hydropower. Because all of these activities impact each other, effective communication and collaboration is essential to integrate management and research efforts across inland fisheries and nonfisheries sectors. Fostering a common language surrounding fisheries and aquatic ecosystem management, developing common goals for these systems, and applying tools (e.g., structured decision making, management strategy evaluation) that incorporate multiple-use objectives, solicit stakeholder input, and define performance metrics for addressing the impacts of water management on all sectors are critical to manager and stakeholder-defined success (see Irwin et al. [2011], for example). In addition, both inland fisheries and nonfisheries sectors are impacted by global change (e.g., climate change, land-use change, and political change). To assure that North American inland fisheries (and, for that matter, all inland ecosystem services throughout the world) are sustainable in the future, development of global change approaches can be pursued in ways that account for uncertainty and provide managers with tools that are actionable (Asrar et al. 2013). Finally, aquaculture and activities that enhance fisheries (e.g., stocking), often considered externalities by fisheries communities in North America, are also important (Bostock et al. 2010) and need to be integrated into an overall framework of inland water and fisheries management. Within the theme of externalities, we identified three specific grand challenges:

GC C.1. Integrate Management and Research Efforts across Sectors

Management goals across fisheries and nonfisheries sectors can be overlapping, conflicting, or mutually dependent. Inland fisheries are often dominated by anthropogenic impacts upon the quantity and quality of freshwater habitats, primarily from externalities (i.e., factors external to the fishing sector and beyond the purview of fisheries management). Though precautionary approaches help prevent and mitigate the spread of fish diseases, invasive species, and pollutants, fisheries managers cannot effectively address these change agents on their own. Fisheries managers can regulate harvest because it is within their mandate and authority to do so; however, they often do not have direct regulatory authority over activities such as water withdrawals, hydropower, flood control, transportation, urbanization, agriculture, mining and oil and gas extraction, forestry, or tourism and recreation, all of which can impact fisheries viability and production. Consequently, identifying common cross-sectoral goals requires not only an understanding of ecosystem processes (Lapointe et al. 2014) but also, more importantly, effective cross-sectoral communication. For example, sector-specific management goals, such as "increase fisheries harvests" or "improve water quality," usually reflect interests of a specific group of stakeholders. Ideally, management objectives under different goals may be mutually beneficial where achieving one objective under one goal may reinforce objectives under other goals. In such cases, resource managers should be able to identify a common agenda (see Kania and Kramer 2011) and promote this synergy across sectors. However, in cases where objectives under different management goals may be conflicting, resource managers can jointly evaluate trade-offs among inland fisheries and other ecosystem services (e.g., using structured decision making). Exercises for evaluating trade-offs, such as scenario-envisioning (Carpenter and Folke 2006) and model simulations (Innes et al. 2007), allow stakeholders, managers, and policy makers to describe how an ecosystem may develop under different assumptions and management practices. In addition, although remote meetings via conference calls or video chats can play a key role in maintaining meaningful dialogue with low financial and personnel costs, in-person meetings, including informal social interactions, are invaluable to forging common understanding and mutual trust (Roux et al. 2008).

As a first step, we recommend that a North American cross-sectoral expert directory be established to make accessible information on personnel with specialized knowledge and skills. There are several existing expert directories in different sectors, such as the U.S. Geological Survey staff profiles, Fisheries and Oceans Canada Scientists Directory, and the American Fisheries Society Membership Directory. Expanding these database frameworks to a cross-sectoral expert directory beyond federal government staff and society members will facilitate accessibility and may encourage exchange of expert skills among sectors. Likewise, developing and adopting a standardized and centralized research data sharing framework will likely be useful for cross-sectoral projects. Data collected via field surveys and research initiatives could be shared in a standardized format and archived by cross-

sectoral themes in a central database that is directly accessible to all sectors through an Internet portal. Data sharing policies are becoming more frequent but the process is still evolving. The U.S. Office of Science and Technology Policy and the Canadian Ministry of Innovation, Science and Economic Development, for example, have both recently mandated data sharing initiatives to promote open and accessible government data, including fish-related data, but guidance on implementation for both jurisdictions is still in the early stages of development.

GC C.2. Work with the Global Change Community to Develop Science to Better Understand the Future Impacts

Conserving and enhancing North American inland systems will require an improved understanding of how global change (e.g., climate change, land-use change, and political change) will influence land–water management and how changes to water quality and quantity and land use will affect inland fisheries. Climate changes to water temperature regimes and precipitation patterns are expected to cause changes in fish populations, fisheries, and their management across multiple levels. For example, temperature changes will affect individual metabolic processes (e.g., Kao et al. 2015a, 2015b) and river discharge magnitude and timing, which will likely affect spawning runs for anadromous fish populations (e.g., Kovach et al. 2013). Species distributions are also expected to shift as some habitats will become increasingly hospitable and others become intolerable in a changing climate (Lynch et al. 2010). Additionally, increases in water demands may draw water usage to other sectors, further modifying aquatic habitat (e.g., instream flow) and fisheries production.

How fish will respond to global change and whether they experience changes in abundance, range expansion or contraction, or extirpation depends on their adaptive capacity (e.g., temperature tolerance and scope, behavioral and phenotypic plasticity, and ability to genetically evolve to changes) and the speed at which niche components of the system (e.g., habitat suitability, community composition) change (Ficke et al. 2007). Compounding factors (e.g., land-use changes, water withdrawals, and pollution) across the landscape can exacerbate climate change–induced stressors. Anticipating which species will be maintained and which will be potentially eliminated by their inability to withstand these system changes is a key challenge for management agencies and their cross-sectoral partners in trying to maximize long-term viability of resource allocations.

GC C.3. Develop Ecologically and Economically Sustainable Aquaculture and Fisheries Enhancements

Aquaculture and fisheries enhancement is a complicated sector (i.e., not always considered part of the inland fisheries sector but also not considered a true externality). Commercial freshwater aquaculture within North America produced approximately 250 kilotons of freshwater and diadromous fish biomass valued at more than $930 million in 2013 (Food and Agriculture Organization of the United Nations 2014). Further, many state and provincial management agencies rely heavily on their own hatchery facilities to either enhance existing recreational fishing opportunities or provide opportunities where they did not previously exist (e.g., Pacific Salmon fishing in the Great Lakes). Enhancement facilities also provide mitigation and recovery of threatened and endangered species throughout North America (e.g., Shovelnose Sturgeon *Scaphirhynchus platorynchus* in Montana). Despite these benefits, aquaculture and fisheries enhancements also can have negative impacts on wild fisheries resources, including ecological and genetic interactions between wild and stocked or escaped cultured fish, nutrient loading from fish farm effluents, and disease transmission to wild populations (Lorenzen et al. 2012). Developing approaches that allow beneficial aquaculture production and use of fisheries enhancements without harm to wild populations or their ecosystems could be a primary goal of the sector.

Given that the demand for fish is likely to increase in the future, new aquaculture and hatchery facilities may be necessary to meet increased demands (Bostock et al. 2010). Predicting the impacts of increased aquaculture prevalence in inland systems will be essential to ensuring an ecologically and economically sustainable fisheries sector in these waterways. Though hatcheries have long held an important position in North American fisheries management, they are often insufficiently evaluated (Lorenzen 2014). Standardized evaluations of the impacts of aquaculture and fisheries enhancement on existing inland fisheries (i.e., consideration of escapement risk that leads to competition for food resources, introduction of nonnative disease organisms, and the potential for both inbreeding and outbreeding depression in a systematic fashion) within the permitting and regulation process would better ensure that aquaculture and hatcheries add value to existing inland fisheries. For instance, Bartley et al. (2007, and references therein) reviewed multiple methods for evaluating environmental costs of aquaculture and other food production sectors, their benefits and weaknesses, robustness, ease of implementation, and impediments to comparing food production among sectors. Compilation and synthesis of best practices in aquaculture facilities and for stock enhancement activities (e.g., Boyd 2003) can assist with appropriate site choice and diminish the potential for unintended consequences of new production facilities, as well as help alleviate contention and misunderstanding in a world with growing food production needs through transparency of process.

NEXT STEPS

Though we recognize that other grand challenges to the management and conservation of North American inland fish and fisheries may be identified from other perspectives (e.g., more site-specific or regional issues that were impossible to capture here), this exercise nevertheless represents a first step in the grand challenges dialogue and we hope that these outcomes stimulate discourse and concerted effort to improve the management and conservation of North American inland fish and fisheries. Certainly, work that improves (1) valuation methods for inland fish and fisheries, (2) governance of inland fish and fisheries to satisfy multiple use and conservation objectives, and (3) consideration of externalities in the management process is necessary. Given the urgency and sensitivity of the social–ecological problems facing inland fish and fisheries, addressing these grand challenges will be an important step to ensuring sustainable use and conservation of these valuable resources, as well as providing broad-based tactical and operational direction for our profession (Table 1), including:

- Use of a common currency for the diverse values of inland fish and fisheries.
- Application of governance structures that promote positive discourse where diverse constituencies are welcome to participate in the fisheries management process.
- Development of tools to assess the impact of externalities and global change on inland fish and fisheries so that fisheries professionals can effectively engage in the greater water policy process.

Additionally, we recognize that similar exercises can *and should* be conducted for other regions around the globe, as well

as for the marine realm. We encourage others to review the outcomes of our exercise and conduct their own grand challenges exercises tailored to their own fisheries and specific needs.

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