Assessment of Inland Fisheries: A Vision for the Future

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Abstract.—The assessment process is fundamental to ensuring that inland fisheries are managed sustainably and valued appropriately so that they can support livelihoods, contribute to food security, and generate other ecosystem services. To that end, a global group of leaders in inland fishery assessment convened to generate a list of recommendations and specific actions for improving assessment of inland fisheries. Recommendations included the needs to assess the global contribution of inland fisheries to food security, develop and implement rigorous approaches to evaluate various inland fishery management actions, develop and implement creative approaches to improve the assessment of illegal fishing activities, and improve statistical data for unreported and unregulated catches in inland waters. The group also identified a need to develop standardized and defensible methods of biological assessment of inland fish and fisheries that include data collection, database management, and data sharing and reporting to reflect diverse ecosystem types. Moreover, it was recommended that assessment be designed to better inform inland fishery management and other sector planning and decision making at the appropriate scales (e.g., integrated water resource management) through stakeholder engagement, valuation of fisheries outputs, and identification of policy alternatives with consideration of trade-offs. The inherent diversity of inland fisheries in terms of ecological, socioeconomic, and governance attributes was recognized throughout the process of developing the suggested actions, including how such attributes combine to provide fisheries-specific contexts for management. Using appropriate and accessible communication channels is critical to more effectively package, present, and transfer information that raises awareness about inland fisheries values and issues; alter human behavior; and influence relevant policy and management actions. Creating mechanisms to facilitate dialogue among the diverse range of stakeholders is equally important. Improved assessment techniques should play a fundamental role in supporting sustainable inland fisheries management and contributing to food security and livelihoods, while also maintaining or improving ecological integrity.

Introduction
Inland fisheries are diverse, spanning a range of sectors (e.g., commercial, recreational, and subsistence) and occurring in very different ecosystems around the globe (e.g., through the ice of frozen lakes in Scandinavia to small forest streams in the United States and the vast floodplain systems of the Mekong basin; Welcomme 2011). Although often cast in the shadow of global marine fisheries, inland fisheries are increasingly recognized for their contributions to food security, livelihoods, human well-being, and the economies of many coun-
tries (Lynch et al. 2016). The United Nations Food and Agricultural Organization (FAO) fishery statistics estimate that 10 million metric tons of freshwater fish are harvested per year, although it is acknowledged that the actual harvest is probably much greater due to unreported and unregulated fisheries (Welcomme et al. 2010). In addition, billions of individual fish are captured and released by anglers in the recreational sector (Cooke and Cowx 2004). Ensuring that inland fisheries are managed to provide ecosystem services that benefit humans while also maintaining biodiversity and ecosystem integrity is crucial, particularly given the many external influences (e.g., hydropower development, irrigation, pollution, and climate change) that impact both aquatic ecosystems (Dudgeon et al. 2006; Vörösmarty et al. 2010) and the fisheries that they support (Welcomme et al. 2010; Beard et al. 2011).

Fishery planning needs to be well informed about all aspects of the resource: the status of fish populations; the nature of existing fisheries; and the social, environmental, and economic issues that shape resource use (McCaflerty et al. 2012). This planning should also be integrated with planning for other, sometimes competing, aquatic ecosystem services (e.g., irrigation, hydropower, and drinking water). Traditionally, fishery management focused primarily on fishing activity and the target populations, but it is now widely recognized that because fisheries and other uses of aquatic resources have direct impacts on the ecosystem, all users need to be managed in an ecosystem context (Beard et al. 2011). Ecosystem management has been defined as "the application of ecological, economic, and social information, options and constraints to achieve desired social benefits within a defined geographic area and over a specified period" (Lackey 1999). This definition implies that the management of different resource uses should be interconnected rather than separate processes that have potentially conflicting objectives and overlapping data needs and require a common decision framework. As such, ecosystem management is "a management philosophy that focuses on desired states rather than system outputs" (Cortner and Moote 1994). This focus on desired states offers a foundation for comparing impacts and, therefore, net benefits of different uses of aquatic resources.

Fishery assessment is fundamental to effective planning and management. Assessment activities in the fishery management cycle are focused on three key questions. Fishery potential—how big could the fishery be? Fishery use—how big is the fishery currently? Fishery impacts—how is the fishery impacting the target populations and the supporting ecosystem? In some jurisdictions, assessment techniques are well developed, with extensive capacity to undertake biological assessment, synthesize data, and use them to inform the fishery management cycle, not unlike an adaptive management approach (Walters 2007) wherein continuous monitoring informs future management options. Nevertheless challenges still remain, including limited fiscal and human resources and the inherent difficulties with assessing fisheries in some waters (e.g., remote locations, complex habitats, and high flows). In some jurisdictions, little capacity or financial resources exist to undertake fishery assessments, or there are inadequate supportive governance structures (e.g., institutions, policy frameworks) to incorporate such information into fisheries management. Without information about local fish stocks and production, it is impossible to manage fisheries effectively or value them adequately so that their importance at local and global scales is appropriately acknowledged.

Given the important role of assessment in ensuring that inland fisheries are managed sustainably in an ecosystem context and in raising awareness about the scale, scope, and value of inland fisheries, the authors convened a meeting of world leaders in fisheries assessment as part of the global conference on inland fisheries held at FAO in Rome in January of 2015. Prior to the meeting, the authors reviewed available literature to generate questions and identify issues or challenges related to assessment of inland fisheries that served as the basis for discussion. Approximately 50 people from many sectors around the globe attended the session and provided input that developed recommendations and possible implementation mechanisms to direct a future
research agenda. That information is summarized here as a vision for the future of inland fisheries in which assessment would be more effective in enabling sustainable management and, therefore, contributing to food security and livelihoods while also maintaining or improving ecological integrity.

The 10 priority recommendations generated by attendees were developed as a series of proposed actions and separated into two themes: six recommendations focus directly on proposed actions to improve assessment of inland fisheries worldwide while four recommendations propose actions and considerations to support these improvements (Figure 1). The recommendations are presented in a logical progression of steps, though the authors recognize that the diversity of inland fishery governance structures and the various spatial scales at which assessments occur suggest that this progression may not be universal and that suitable actors for addressing each recommendation may also vary among fisheries and jurisdictions.

**Assessment Recommendations**

1. Recognize the large number and high diversity of small inland fisheries

   **Context.**—Much of the world’s inland fisheries catch comes from a large number of small lakes, streams, and wetlands that are charac-

![Assessment Recommendations Diagram]

**Supporting Recommendations**

- Manage fisheries based on scientific evidence
- Communicate inland fisheries status, threats, management, and policies
- Engage stakeholders in management processes
- Manage fisheries within broad ecosystem and socio-political contexts

*Figure 1.*—The 10 priority recommendations derived by attendees of the fisheries assessment symposium as part of the Global Conference on Inland Fisheries held at the Food and Agriculture Organization of the United Nations in Rome in January of 2015. The recommendations are separated into two overarching themes: recommendations for improving inland fishery assessments, and recommendations for supporting these improvements. Each category has been listed in descending order as a logical progression.
terized by great diversity in natural ecological conditions (Bachman et al. 1996; Soranno et al. 2010), anthropogenic habitat modifications (Khoa et al. 2005; Vörösmarty et al. 2010), fishing pressure (Post and Parkinson 2012), socioeconomic attributes of fishers (Smith et al. 2005), and governance arrangements (Almeida et al. 2009; Snell et al. 2013). All of these factors affect realized fisheries outcomes, management options, and the outcomes that can potentially be achieved: one-size-fits-all management is unlikely to be a good policy (Carpenter and Brock 2004; Castello et al. 2011; Post and Parkinson 2012).

**Recommendation.**—Recognize and account for the inherent diversity of inland fisheries (in terms of ecological, socioeconomic, and governance attributes) in assessment processes and in providing management advice.

**Proposed actions.**—There is a need for development of assessment methods that support differentiated management appropriate to local conditions. This requires, first, a qualitative appreciation of how different attributes vary among fisheries and how they interact at local levels to drive outcomes and management options for specific fisheries (Carpenter and Brock 2004; Lorenzen 2008). It requires, second, methods for assessing outcomes and management options for individual fisheries. Two alternative, but not mutually exclusive, approaches may be taken to this end. One approach is to develop simple assessment tools (and methods for employing them) that may be used locally, possibly by nonscientists (the “barefoot ecologist” approach, Prince 2003). A suite of fisheries assessment methods for data-poor stocks are also now available (Carruthers et al. 2014). Another approach is through use of empirical models. Empirical studies explore the statistical relationships between fisheries response variables (e.g., harvest, abundance) and explanatory variables such as fishing effort, primary productivity, or the presence–absence of anthropogenic habitat modifications and provide models of fish production and potential yield. Information from multiple fisheries can be combined to capitalize on the variability between them and derive empirical models. Empirical models have been used to describe how fishery yield or fish abundance responds to variation in environmental factors (Ryder et al. 1974; Bachman et al. 1996), anthropogenic habitat modifications (Pretty et al. 2003; Khoa et al. 2005), fishing effort (Lorenzen et al. 2006), and fisheries management arrangements (Almeida et al. 2009).

(2) Expand the range of tools for fishery assessment

**Context.**—Technological innovation, creativity, and need have resulted in numerous options for expanding the traditional fishery assessment toolbox. For example, surveys and mobile technologies can tap into the collective experience and wisdom of inland fishers. Survey data can be collected from fish markets (Nasir and Khalid 2013), from landing sites (Abobi et al. 2014), government statistics (e.g., household surveys; IFRoDI 2013), and by mail or phone (Dorow and Arlinghaus 2011). Anglers can also voluntarily report information through paper diaries (Cooke et al. 2000), Web sites (Muñoz and Taylor 2013; Martin et al. 2014), or mobile technologies (Papenfuss et al. 2015). Recent advances in stable isotope techniques allow for inference of fish habitat associations and diet from the microchemistry of calcified structures (Pouilly et al. 2014). Similarly, environmental DNA (eDNA) can be used to assess species presence–absence (Lodge et al. 2012) and perhaps biomass (Takahara et al. 2012) and hydroacoustics used to assess abundance, distribution, and behavior (Getabu et al. 2003). Finally, the inland fishery management toolbox can be expanded via remote sensing at local and regional scales. Examples of remote sensing at the local scale include unmanned vehicles (Davis et al. 1997; Jensen et al. 2014), stationary cameras (Sunger et al. 2012), and receiver and sensor arrays (Hall 2007). Remote sensing of inland fish and fisheries at regional scales can be either direct (e.g., satellite image-based harvest estimates; Al-Abdulrazzak and Pauly 2014) or indirect (e.g., satellite-derived estimates of chlorophyll a, geographic information system-based correlates of fish productivity; Fisher 2013; Lesht et al. 2013). These novel approaches to data collection address many of
the challenges associated with the assessment of inland fisheries in that they tend to be non-invasive, rapid, and appropriate for systems or resources that are difficult to sample or for which the capacity for sampling is limited (especially over broad temporal or spatial scales). The contribution of a range of data from such methods provides multiple sources of information by which the accuracy of fisheries assessments can be rapidly improved.

**Recommendation.**—Expand the range of tools for assessment through the incorporation, validation, and standardization of new and integrated sampling methods (e.g., stakeholder and local ecological knowledge, household surveys, mobile technologies, microchemistry, eDNA, hydroacoustics, remote sensing, and geographic information systems).

**Proposed actions.**—Researchers and managers should conduct experiments and pilot studies aimed at advancing and refining these tools and determining their strengths, weaknesses, benefits, and limitations for use in inland fishery assessment. For example, significant advances in eDNA are required before this tool can be used to estimate abundance (Lodge et al. 2012), and hydroacoustic techniques are currently constrained by environmental and morphological considerations such as turbulence and substrate type (Lucas and Baras 2000; Maxwell 2007). Validation of these tools through careful observation and comparison against contemporary tools will show the extent to which data are precise and unbiased for a given set of conditions and procedures. Comparison will show the extent to which a novel tool complements or is an alternative to a contemporary tool. Mobile technologies are one example in that they are effectively angler diaries in digital format. While angler diaries (whether contemporary or digital) cannot replace formal surveys due to nonrandom and unreliable participation (Cooke et al. 2000), reasonable agreement between data from a popular recreational fishing application and both mail and creel surveys (see Martin et al. 2014; also Papenfuss et al. 2015) suggests that widespread use via proper incentives (e.g., information, feedback, and community) can largely overcome participation issues. Finally, managers and researchers should be encouraged to publish their findings to develop standards for inland fishery assessment methodology. Communication will encourage collaboration and innovation (while discouraging duplication), and the novelty of many of these emerging tools is a rare opportunity to coordinate and standardize both efforts and methods across diverse inland fisheries.

(3) **Standardize methods of assessment of inland fish and fisheries**

**Context.**—Standardization of industrial processes, languages, measurements, and data collection techniques has been essential for world progress (Nesmith 1985; Bonar et al. 2009). Routine data collection and assessment techniques have been commonly standardized in many scientific professions, including medicine (Beers and Berkow 1999), meteorology (Lockhart 2003; Schiesl 2003), geology (Assaad et al. 2004), and water chemistry (Eaton et al. 2005). Standardizing the assessment of inland fish and fisheries (i.e., collection and reporting of fisheries data using a few similar methods) offers many advantages as well (Bonar and Hubert 2002; Bonar et al. 2009). These include a much improved ability to compare data across regions or time, thus meeting needs for larger regional or global scale assessments necessary for setting broad-scale regulations, identifying effects of global climate change, and evaluating adequacy of global food supplies. Standardization can also vastly improve communication across political boundaries and control bias associated with different sampling (e.g., netting, electrofishing, and hydroacoustics) and data reporting techniques. When fishery biologists have used standard assessment techniques, benefits have been striking. For example, Homer Swingle (1950, 1956) developed early standard techniques to study fish populations in southeastern U.S. ponds. The information Swingle obtained using these standard techniques was instrumental in understanding basic biology of fishes and how to successfully manage them for food and sport and was used by organizations worldwide to improve fish production (Byrd 1973). If the data collection
methods were not standardized, cross-site or cross-time analyses would require calibration and would always contain significant uncertainty.

Recommendation.—Further develop standardized and defensible methods of biological assessment of inland fish and fisheries that include data collection, sharing, and reporting to reflect diverse ecosystem types and enable intra- and cross-sectoral comparisons.

Proposed actions.—Techniques to effectively sample freshwater fishes have existed for centuries. However, getting people to change the techniques that they are currently using to adopt a standard is challenging, often because of potential interference with long-term data sets, political rivalry among agencies and countries, and tradition (Bonar and Hubert 2002). Integrating social with biological science is essential to standardization (see Bonar and Fraidenburg 2010). Developing standard methods and encouraging compliance with standardized procedures requires clear statements of the advantages of using standardized methods; development of standards within the authority of widely respected groups that transcend political boundaries, such as the World Fisheries Congress, the American Fisheries Society, the European Committee for Standardization, or the International Organization for Standardization; inclusion of many varied parties in standards development; and, depending on the situation, either requiring or not requiring methods to be adopted. These techniques are currently being used to develop standards for increasingly larger regions. For example, the American Fisheries Society recently recommended standard techniques for sampling North American freshwater fish populations, an ongoing process involving 284 biologists from more than 100 North American organizations (Bonar et al. 2009). The European community has a continuing program to develop fish sampling standards involving many European countries (e.g., CEN 2003; CEN 2005; and others). Standardization on even larger, global scales has been discussed—an increasingly important issue with advances in worldwide communication and global threats to freshwater fisheries. For situations in which methods standardization is not possible among areas, gear calibration and comparison techniques allow gear types to be compared (e.g., Peterson and Paukert 2009) or ground-truthed for comparison. However, reducing the number of situations in which conversion factors must be applied improves comparison and communication. Finally, recognition that widespread standardization is not an immediate outcome of developing standard procedures is important. Adoption of standard procedures often takes time and requires continued effort. Even small movement toward standardization, however, improves communication and data analysis. Therefore, patience and persistence are necessary attributes to those who wish to standardize.

(4) Improve estimation and reporting of relevant inland fishery statistics

Context.—Reliable estimates of inland fishery production, consumption of inland fishery products, participation in fishing, and other relevant indicators are important to support adequate valuation of inland fisheries and consideration in sectoral and intersectoral policies. The development of relevant and comparable indicators, however, is in itself challenging, given the diversity of the fishery sector and the products that it provides (e.g., fish that are traded, consumed for subsistence or exchanged through social networks, recreational fishing opportunities that need not involve any harvest; Smith et al. 2005). Moreover, the diffuse and widely distributed nature of most inland fisheries and associated landing locations and markets often precludes the use of the reporting systems commonly used in marine commercial fisheries. Carefully designed sampling schemes are rarely used, the exceptions being large water bodies such as reservoirs and commercial fishing concessions. As a result, reliable and relevant inland fisheries statistics are often absent. Consequently, inland fisheries remain poorly reported or even ignored in national statistics and in considerations of food security. A systematic undervaluation of the contribution of inland fisheries may extend throughout the value chain.
Recommendation.—Improve the estimation and reporting of reliable and relevant inland fisheries statistics through methods that account for the diversity of products provided by the fishery sector and its diffuse and distributed nature.

Proposed action.—A reform of systems for estimating and reporting inland fisheries statistics is long overdue. Reforming reporting systems in a coordinated manner at the local, national, and international levels would greatly strengthen the global statistics provided by FAO. Due to the diversity and diffuse nature of inland fisheries, development of effective data collection systems requires a good understanding of fisheries and the products that they provide. In addition to catch reporting systems covering major landing sites or markets, a variety of approaches have been used to improve estimates of catches, fishing effort, and other indicators. Household surveys can be used to provide valuable data when a substantial share of the catch is neither marketed nor landed at defined landing sites (e.g., for subsistence fisheries; FAO 2014) and are potentially useful for gathering assessment data. Data generated from household surveys may include estimating food consumption, household income, and food production decisions, contribution of fisheries products to livelihoods, time, and capital investment in fishing activities (Beaman and Dillon 2012). It is also possible to collect detailed data suitable for use in fisheries assessments from household surveys, for example on catches from different water bodies or habitats, species composition, seasonal change in catch composition, and use of fishing gears (Khoa et al. 2005; Hortle 2007; Almeida et al. 2009).

(5) Evaluate the effectiveness and impacts of inland fisheries enhancements through assessment

Context.—Active enhancement of inland fisheries through stocking or habitat modifications is widespread. For example, in the United States, state fisheries management agencies release more than $1.7 \times 10^9$ hatchery-reared fish of more than 100 species and stocks annually, and state agencies expend 21% of their budgets on practical enhancement activities (Ross and Loomis 1999; Halverson 2008). In China, state and private entities operate fisheries enhancements in more than 80% of the country’s vast acreage of reservoirs, yielding more than 2.5 million metric tons of fish annually (Li 1999; Miao 2009). Rural people in the tropics implement a plethora of fisheries enhancement measures in public, communal, or private water bodies (Welcomme and Bartley 1998; Amilhat et al. 2009). Fisheries enhancements combine elements of capture fisheries and aquaculture and are subject to specific management considerations. Enhancements can be effective in increasing fisheries yields or opportunities for recreational fishing and wider socioeconomic benefits, provided that conditions are conducive and the enhancement measures well designed. In practice, however, many enhancements are likely to be ineffective and some have caused demonstrated ecological damage (Cowx 1994; Lorenzen et al. 2012). Unfortunately, the extent of inland fisheries enhancements, their contribution to catches and other fishery performance measures, and their ecological impacts are poorly documented and evaluated.

Recommendation.—Quantify the contribution that enhancement measures such as stocking or habitat modifications make to inland fisheries production and assess where and when such active measures can contribute positively to management outcomes and when they should be avoided.

Proposed actions.—Collection of data to quantify the contribution of enhancements to inland fisheries harvest and other fisheries performance metrics should be encouraged as an integral part of the assessment process. Separate recording of catches derived from enhancements in fisheries statistics is a first step, even though this is neither straightforward nor sufficient to assess net contributions (Klinger et al. 2012). Scientific knowledge and assessment tools have matured to the extent that they can be used in an effective and timely manner to improve emerging and established enhancements. Continued progress in the assessment and management of enhancements
will likely require interdisciplinary studies that combine theory development with experimental tests of key assumptions and long-term manipulative experiments (Lorenzen 2014). The authors further encourage the development of validated and standardized methods for reforming enhancements (Cowx 1994; Lorenzen et al. 2010).

(6) Synthesize global inland fisheries status and drivers

Context.—The global harvest of inland fisheries reported to FAO has slowly increased by about 0.15 metric tons per year since 1950—11.6 million metric tons in 2012. This is in stark contrast to the global harvest of marine fisheries that plateaued around 80 million metric tons in 1990 (FAO 2014). Although these data indicate that inland fisheries currently comprise only 11–12% of the global harvest, some have speculated that the inland fisheries harvest is markedly underestimated, owing to inadequate resources to sufficiently record catches; the exclusion of subsistence, artisanal, and recreational harvest; or deliberate misrepresentation of reported landings (Cooke and Cowx 2004; Allan et al. 2005; Welcomme et al. 2010; Beard et al. 2011). FAO argues that “inland waters remains the most difficult subsector for which to obtain reliable capture production statistics” and states that catches may even be overestimated in some years given the high level of interannual variation reported by some countries (FAO 2014). Therefore, scientists unanimously agree on the probable inaccuracy of the reported harvest from inland fisheries at the global scale. Beard et al. (2011) argued that a less-biased global estimate could lead to greater investment in the management and restoration of inland fisheries as the sector faces increasing competition with hydropower, irrigated agriculture, and transportation for the use of freshwater.

Recommendation.—Improve global models for estimating inland fish production through regional or subregional validation, standardization of sampling approaches, and consideration of more potential explanatory factors (e.g., climate, latitude, catchment and water body characteristics, migratory status of species).

Proposed actions.—Simple models that predict inland fish production based on lake size alone suggest that sustainable production could be as high as 90 million metric tons (Welcomme 2011). Although Welcomme (2011) acknowledged that as a “crude” estimate, it suggests that more refined attempts to estimate global inland fish production were possible. To this end, the development of multiple modeling approaches is encouraged. For example, at the subcontinent or regional scales at which inland fisheries production is more reliably monitored, scientists could develop standardized methods to measure relatively simple in situ characteristics of water bodies (e.g., Secchi disk depth for lakes, mean discharge for river systems, mean surface water temperature, and mean chlorophyll a). These data could be used to develop predictive models, with separate ones likely to be needed for rivers and lakes (e.g., Welcomme and Hagborg 1977; Schlesinger and Regier 1982). Other models to predict fish production could be developed that rely on remotely sensed data (e.g., atmospheric climate, surface water temperature, chlorophyll a, land cover in the catchment, water basin morphometry, human population density, or other economic development indicators) available from satellite imagery or geographical information system data layers. These models could be global in scope or as broad as reliable inland fish production data permit. Ideally, these remotely sensed models would be validated with the regional models that use in situ measurements. Finally, special research focus should be allocated towards the continents of Asia and Africa, where, in 2012, 13 countries comprised nearly 75% of the global inland fishery harvest (FAO 2014). Applying these complementary methods within these productive regions would yield multiple benefits. First, it could identify key drivers (i.e., land use, productivity, and human population characteristics) of inland fisheries harvest and potentially provide a sense of how a changing ecosystem could affect inland fisheries. Second, given that both Asia and Africa possess a wide diversity of lakes and rivers, these
methods could begin to reveal the relative contribution of these water body types to inland fisheries production. Finally, a more accurate estimate of inland fishery production on these continents would greatly improve the accuracy of the global estimate.

Supporting Recommendations

(1) Manage fisheries based on scientific evidence

**Context.**—There is growing recognition that resource management actions tend to be based on intuition or past experiences of the manager (i.e., faith-based fisheries; Pullin et al. 2004; Hilborn 2006), even when credible evidence has been synthesized and suggests a different approach (Walsh et al. 2015). There have been calls for the environmental and conservation world to draw upon techniques used in the medical realm to synthesize information such that decisions are based on objective scientific evidence (Pullin and Knight 2001). Systematic reviews (which incorporate meta-analysis) ensure accessibility of the best available evidence and should yield a more efficient and unbiased platform for decision making (Pullin and Stewart 2006), such that environmental managers do more good than harm (Pullin and Knight 2009). Meta-analyses are already used in aquatic science (e.g., Smokorowski and Pratt 2007; Chapman et al. 2014) but tend to be done with less rigor than a formal, systematic review. Indeed, broad consultation, peer review of the science, and use of systematic reviews to facilitate evidence-based conservation and management are essential, yet lacking, despite a receptive scientific community and the existence of frameworks for doing so (i.e., Pullin and Stewart 2006).

**Recommendation.**—Develop and implement rigorous approaches to evaluate various inland fisheries management actions to provide the evidence base to support management, mitigation, compensation, and restoration and enhancement activities

**Proposed actions.**—To move away from a faith-based approach to fishery management, a number of specific actions are recommended. For example, resource management agencies could incorporate large-scale management experiments that use a before-after-control-impact or adaptive management approach to evaluate the effectiveness of their actions. The fishery management community should conduct systematic reviews (Pullin and Knight 2001) on common management interventions relevant to inland fisheries (e.g., is fish passage effective at maintaining and restoring river connectivity, and if so, under what conditions? Do freshwater protected areas benefit fish populations outside of the protected area such that they are a viable management strategy? Do voluntary regulations embraced by fishers work as well as those that are dictated and enforced by regulators?). Finally, fishery managers need to rethink the basis for their various management decisions and use an evidence-based approach over simply following intuition or tradition. Doing so will ensure that limited resources are deployed and utilized appropriately and that management actions will be more likely to produce the beneficial outcomes they were designed to achieve.

(2) Communicate inland fisheries status, threats, and management and policies

**Context.**—The public is generally unaware of the benefits derived from inland fish and fisheries (Lynch et al. 2016) and their current status as the most imperiled group of animals worldwide (Strayer and Dudgeon 2010). This lack of awareness suggests that effective communication and engagement models are not being successfully implemented by fisheries professionals or their agencies. Increasingly, researchers are becoming aware of the need to garner public support for research and conservation initiatives (Cooke et al. 2013a). Information gathered from local fishers and experts has been used to guide research efforts to success and improved socioeconomic outcomes (Johannes and Neis 2007; Hind 2015). There are also numerous instances of research and conservation activities that have been made successful as a result of the participation of citizen scientists, fishers, and others who contribute time, personal finances, and expertise.
to support such endeavors (Granek et al. 2008; Fairclough et al. 2014). The success or failure of conservation efforts has been largely determined by stakeholder support in some cases (Jentoft et al. 2012; Sawchuk et al. 2015).

Yet, though it should be considered an essential part of the process, the outcomes of research projects or conservation initiatives are not widely communicated to interested stakeholders (Hulme 2014; Young et al. 2014). To encourage a broader understanding of the issues currently facing inland fish and fisheries, positive relationships, and ongoing support for proposed solutions, fisheries professionals should adopt strategies for communicating more effectively with the general public (Cooke et al. 2013a). Ultimately, a more engaged and better informed populace is more likely to have a positive effect on evidence-driven policy development (Cooke et al. 2013a; Young et al. 2014).

**Recommendation.**—Develop a communications plan that uses appropriate and accessible communication channels to more effectively package, present, and transfer information on inland fisheries to a range of target audiences so as to raise awareness of inland fisheries values and issues, impact human behavior, and influence relevant policy and management.

**Proposed actions.**—Improvements in fisheries science engagement should first be addressed by developing strategies for effective communication, including the identification of barriers to public engagement (see Cooke et al. 2013a) and suitable methods for overcoming these barriers. Effective methods of communication will vary among target audiences, among regions, and even at the fishery scale, suggesting that strategies should not attempt a one-size-fits-all model for communication, but be based on stakeholder research, fisher knowledge, and other fishery-specific information (Hind 2015). For example, some regions may be more likely to use cell phone technology (applications) than others, but may be limited by technological differences (i.e., many African regions have extensive access to cell phones but not smartphones and are, thereby, limited to what applications may be used; Bratton 2013). Second, training in communications for researchers should be considered an institutional priority, and funding bodies should consider incorporating standards for evaluating outreach efforts and quality to support this need. Information about outreach and knowledge transfer is not generally included as a mandatory part of training, nor has this need for improved communication and engagement been incorporated into institutional standards (Cvitanovic et al. 2015).

(3) Engage stakeholders in management processes

**Context.**—Dialogue between fishery professionals and stakeholders has traditionally been unidirectional, for example, with research outcomes translated to policy or management initiatives and instituted as a top-down mechanism (Stöhr et al. 2014). However, the need for improved dialogue with stakeholders has become recognized within the scientific and fisheries management communities and, with it, the need for that dialogue to be meaningful, such that it allows for development of trusting partnerships and ongoing relationships (Reed et al. 2014; Sawchuk et al. 2015). The term “two-way dialogue” refers to a more open communication process in which stakeholders can provide information, perspectives, and views on key issues to researchers, managers, and policymakers.

Resource research and management needs to be viewed as a symbiotic exercise in which local experts and stakeholders provide scientists with locally relevant details and community context, while scientists and management provide local communities with the expertise required to address that context (Kettle et al. 2014). Improved two-way dialogue also provides additional opportunities for education, which has been shown to increase the effectiveness of voluntary adherence to regulations in some sectors (i.e., in recreational fisheries; Cooke et al. 2013b). Moreover, encouraging voluntary adherence to regulations and improving access to education (e.g., best practices for fishers) greatly reduces the need for enforcement and cumbersome regulatory processes (Grafton 2005; Cooke et al. 2013b).
Recommendation.—Create mechanisms to facilitate dialogue between and among diverse stakeholders internal and external to the sector.

Proposed actions.—Prior to any inland fisheries management action, key stakeholders should be identified (see Aanesen et al. 2014 for a detailed discussion about stakeholder types and identification processes) and adequate consultation mechanisms should be instituted and followed. Consultation serves to build more positive relationships and increase the likelihood of adherence to voluntary regulations (Cochrane 2001). Further, the consultation process can be used to develop balanced stakeholder networks to address any issues of equity among stakeholders (Grafton 2005).

During research or management processes (including assessment), dialogue points should be built into management and research timelines such that communication occurs at frequent and regular intervals (Ratner and Smith 2014). Not only does formalizing the dialogue process support efforts to increase procedural transparency, but it can also serve as a check and balance function for monitoring the effectiveness of the process (Ratner and Smith 2014). In cases where conflict situations are a concern, dialogue should be facilitated by experienced intermediaries (Johnson and Griffith 2010). Finally, it is crucial to maintain ongoing two-way dialogue and partnerships with stakeholders. Thus, efforts to maintain two-way dialogue should include the development of partnerships with local fisheries groups, nongovernmental organizations, and other appropriate partners (Aanesen et al. 2014).

The Way Forward—Science to Support Action: Managing Fisheries within Broad Ecosystem and Sociopolitical Contexts

It is now widely recognized that fisheries must be managed in a broad context—one that recognizes the influence and dependency of fishing activities on the ecosystems that support them; on other uses of aquatic resources; and on the socioeconomic, governance, and policy contexts that shape fishery resource use (McCafferty et al. 2012). Inland fisheries are particularly affected by other sectors that place demands on freshwater resources (biodiversity conservation, agriculture, industry, mining, and urban development), but also by impacts within catchments (forestry, sedimentation) and increasingly by climate change. To operate within this complex and shifting milieu, fisheries science, management, and policy need to be fully integrated with these wider sectors and their decision support frameworks. Fishery assessments that produce complex models and harvest predictions must be able to present such information in language and formats that inform fishery activities but are also accessible to the different sectors engaged in land and water management and policy.

Assessments should inform inland fishery management as well as other sector planning and decision making (e.g., environmental flows, integrated water resource management) at appropriate scales (e.g., river basin, bioclimatic region, and jurisdiction) through stakeholder engagement; valuation of ecosystem services, including fisheries outputs; and evaluation of policy alternatives with consideration of trade-offs. The recommendations prioritized by the symposium attendees and the thought leaders involved with this paper serve to provide a globally informed template for pursuing improved assessment and management of inland fisheries. These changes would be further supported by the broader recommendations prioritized by the group (supporting recommendations) that will help to ensure that the assessment and management components of contemporary resource management are integrated. It is our collective hope that the changes and improvements recommended for the assessment process provide practitioners with the forward-looking ideas and tools necessary to generate sustainable inland fisheries. If implemented, these recommendations have the potential to shape science-based management at regional and global scales. Failure to do so will further retard our collective ability to sustainably manage inland fisheries not only in terms of sector-based threats like overhar-
vest, but also in terms of external threats such as habitat alteration and water taking, which are permanently altering the fishery production of inland waters.

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