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Freshwater, Fish and the Future

Proceedings of the Global Cross-Sectoral Conference

American Fisheries Society

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Foreword

Fisheries and Aquaculture Department, Food and Agriculture Organization of the United Nations

The Food and Agriculture Organization of the United Nations (FAO) has a long tradition of promoting responsible fisheries throughout the world; 2015 marked the 20th anniversary of the FAO Code of Conduct for Responsible Fisheries. The code is a landmark of international cooperation and agreed set of guidelines and principles to help develop, manage, and conserve the world's fishery resources for the benefit of present and future generations. However, more is needed, especially for the world's inland fishery resources and the habitats that support them. The FAO and our global partners are facing numerous challenges in regards to inland aquatic ecosystems and their fishery resources.

Probably the most significant challenge is the competition for freshwater resources. Currently, about 9% of the freshwater from rivers, lakes, and groundwater is withdrawn for human use. Seventy percent of this water is abstracted or diverted for agriculture, industry takes another 20%, and domestic uses account for another 10%. These withdrawals have significantly degraded the aquatic habitat and fishery resources. However, agriculture is a key player in global efforts to reduce hunger and poverty. Fisheries and agriculture need to become closer partners. Fisheries are often called a "nonconsumptive" use of water. This is not exactly true. If you manage a river for fish, you may lose or reduce the use of that water for hydroelectricity or irrigation. The fishery sector needs to communicate win–win situations where people can have fish and irrigated agriculture and electricity. Happily, there are examples, and these need to be communicated more broadly.

Dealing with the multiple users of freshwater is essentially a governance issue. However, international and national efforts to fully integrate inland fisheries into the broader governance and development agenda have not been overly successful. Important publications and processes have given much more attention to domestic uses of water, to marine and coastal issues, or to agriculture production over inland fishery production. The FAO and partners are now striving to help bring all food producing sectors together in a synergistic manner.

A necessary component to support governance is adequate information. More than half of the catch from inland waters is not reported to species—we do not know how much and we do not know what is being captured. The FAO has a special strategy for improving information on status and trends of capture fisheries to increase the knowledge base.

However, inland fisheries are more than metric tons harvested; what this harvest contributes to nutrition and livelihoods is the important factor. Fish provide significant and affordable protein, minerals, and micronutrients to millions of people in developing areas. A small, freshwater fish from the Mekong River about the size of an index finger can provide a child's daily requirement of iron and zinc; similar small indigenous species of fish are a valuable component of people's diet and culture around the world.

The health of our planet, our own health, and future food security depend on how we treat aquatic ecosystems. To provide wider ecosystem stewardship and improved governance of the sector, FAO is advancing the Blue Growth Initiative as a coherent framework for the sustainable and socioeconomic management of our aquatic resources. Although there is a strong framework for fisheries and aquaculture already in place with the FAO Code of Conduct for Responsible Fisheries, the challenge is to provide incentives and adequate resources to adapt and implement this framework at local, national, and regional levels in order to secure political commitment and governance reform.

The proceedings and recommendation of the global conference, Freshwater, Fish and the Future, will contribute substantially to this global initiative and the core work of FAO and other United Nations agencies. The partnership between FAO and Michigan State University, formalized at the conference, will help to further promote the principles of responsible fisheries and blue growth. The Fisheries and Aquaculture Department of FAO is pleased to be a partner in this endeavor and offer the information in this book to those charged with developing, managing, and conserving the world's inland fishery resources.

Árni Mathiesen
Assistant Director-General
Food and Agriculture Organization of the United Nations
Fisheries and Aquaculture Department

Foreword

Michigan State University

Inland fisheries have long been a quiet but vital component of food and economic security around the world. Yet the voices of those most dependent on inland fisheries often are drowned out by louder, more powerful interests competing for aquatic resources for use in agriculture, energy, and economic development.

We believe that inland fisheries and aquaculture have a great capacity not just to sustain poor and disadvantaged communities around the world, but to elevate them. That is why I was pleased to be in Rome in 2015 to help open the global conference on inland fisheries. This conference brought together experts from various sectors from more than 40 nations, including a large number of early career scientists and women (40% female speakers), because the challenges facing inland fisheries require new cross-sectoral approaches and the involvement of all stakeholders in freshwater resources.

We need to elevate the profile of inland fisheries and aquaculture in global discussions on food and economic security and on sustainable land development and water management. Based upon the thought-provoking presentations and discussions at the Rome conference, a set of recommendations—10 steps to responsible inland fisheries—were developed that we hope will provide the foundation for a new international approach to ensuring that the true value of inland fisheries is recognized in resource allocation decisions.

Back home in Michigan, we are acutely aware of the fragility of freshwater fisheries. Our waters have suffered greatly from pollution, overfishing, and the introduction of invasive species. Our experience in restoring the Great Lakes across boundaries and borders provides a great example of the power of international partnerships and cooperation.

Beyond the conference, Michigan State University (MSU) and the Food and Agriculture Organization of the United Nations (FAO) are strengthening our relationship through joint studies linking societal well-being and food security to the quality and quantity of freshwater habitats and local fish populations. On behalf of FAO and MSU, Árni Mathiesen and I signed a memorandum of understanding to collaborate on inland fisheries educational programs. This includes resource mobilization, capacity building and training, new faculty, internships, fellowships, visiting scholars, and sharing and disseminating information while advocating for our common goals.

Inland fisheries represent an important component of a growing, global blue growth economy. This conference proceedings serves as a roadmap demonstrating how to assess the world's inland fisheries and freshwater resources and how to optimize and protect them.

Lou Anna K. Simon, Ph.D.
President
Michigan State University

Preface

The purpose of this book, and the global conference (www.inlandfisheries.org), is to elevate the significance of freshwater fisheries throughout the world so that fishery managers and the people that depend on freshwater fisheries will have a voice when policymakers make decisions that impact their viability and productivity. All too often, inland fisheries are not appropriately valued as to their critical role in food security, and worse yet, they are not even considered when policymakers decide on the use, allocation, and alteration of freshwater resources in their communities and nations. When governments decide to build dams for power generation and flood control, the impacts on the nearby local communities and on the freshwater ecosystems are too often not considered or, if considered, not valued appropriately. Much of this is due to the fisheries community not being able to provide accurate assessments of the fisheries or the needed economic metrics that allow for decision makers to make informed decisions as to overall costs and benefits of their decisions related to the use of their freshwater resources. In addition, the oftentimes multijurisdictional nature of freshwater systems further complicates decision making given the differing priorities of the various governments that control the water and allied fish habitats that provide the basis for the productivity of local and regional fisheries. The information in this book highlights the importance of freshwater fish, their habitats, and their fisheries to society. The intent of this book is to describe the current state of the knowledge and future information needs that will allow for fisheries sustainability, which in turn directly or indirectly provides for the health, well-being, and prosperity of human communities throughout the world.

It has been a distinct pleasure to interact with such dedicated and innovative fisheries and water professionals and allied policymakers to enhance the visibility and importance of freshwater fisheries to the world. In particular, the phenomenal cooperation between Michigan State University and the Food and Agriculture Organization of the United Nations (FAO) is particularly noteworthy, as without each other's support, a project of this magnitude could not have happened. At Michigan State University (MSU), the unfailing encouragement and support of President Lou Anna K Simon was critical in mobilizing the resources to not only design and implement this ambitious program, but to design a future memorandum of understanding with FAO (see www.inlandfisheries.org) that should enable others to continue the momentum that this conference and book established. The FAO has realized that developing and managing the world's freshwater ecosystems for improved food security and poverty alleviation is a task no one organization can accomplish on its own. Partnerships will be essential in meeting the United Nations' sustainable development goals, as well as fulfilling the mandate of FAO. Mr Árni Mathiesen, Assistant Director-General of FAO Fisheries and Aquaculture Department, was aware of the importance of raising the profile of freshwater fisheries throughout the world and, like MSU President Simon, gave full support to the conference. We also had tremendous support from the American Fisheries Society and, in particular, Beth Beard, who designed the needed communication products that provided and continues to provide essential information in a user-friendly format for all to access via the Web interface. Additional support was provided by the Australian Centre for International Agriculture Research and the Great Lakes Fishery Commission.

No project is ever accomplished without many people providing innovative ideas and just plain hard work in making things happen. There are numerous people from around the world that were instrumental in making the conference and this book a success. In particular, we must acknowledge the steering committee that worked diligently to ensure that this ambitious conference would occur and provided the platform that was needed to improve our understanding of the state of the global fisheries resources and the informational needs that allows for their future sustainability. These include those people that were members of the organizing committee and the steering committee and the panel chairs, who are listed at the end of this preface. It is with deep gratitude that we acknowledge the efforts of Drs. Christopher Goddard and Nancy Leonard for their lead on facilitating the editorial process of this book. Each spent numerous hours working constructively with the authors to make this book as complete and representative as possible. Additionally, Dr. Leonard spent four months working on assignment at FAO, where she helped with the myriad details related to this conference, which were essential to its successful execution and future value. Her adept people skills and intimate knowledge of multistake holder, multijurisdictional fisheries, and aquatic resource management provided essential ingredients for the success of the global conference and this book. Bill would like to thank his colleagues in the American Fisheries Society, in particular the Past Presidents' Council, his colleagues at Michigan State University, and his current and former graduate students who have inspired him throughout his career to dream big and act bigger to improve the state of the world's freshwater fisheries and their habitats. Last, no person is an island unto themselves, and without the unfailing belief, love, and support of Bill's wife, Evelyn, and his English springer spaniel, Teddy, this project would never have been completed. Devin would like to gratefully acknowledge the support of colleagues throughout the world and at FAO (especially Robin Welcomme, the former chief of the Inland Water Resources and Aquaculture Service at FAO), who gave up their valuable time to make the conference a success. The conference would not have been possible at FAO headquarters without the daily administrative and logistic support of Ms. Cristiana Fusconi and the enthusiasm of Mr. Felix Marttin. It is our hope that we have contributed to enhancing the visibility and value of the global freshwater fisheries resources, and through these efforts, freshwater fishes remain an ever present feature of the aquatic landscape and a highly valued component of human civilization. For we believe as fish go, so go humans!

William W. Taylor
Devin M. Bartley

Organizing Committee

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The Rome Declaration: Ten Steps to Responsible Inland Fisheries[1]

Step 1: Improve the Assessment of Biological Production to Enable Science-Based Management

Accurate and complete information about fishery production from inland waters is lacking at local, national and global levels. Governments often lack the resources or capacity to collect such information due to the diverse and dispersed nature of many inland fisheries. There is much scope for developing and refining biological assessment tools to facilitate science-based management.

Implementation recommendations

- Develop, promote and support standardized methods for the assessment of inland fisheries harvest and aquaculture production including: data collection (including traditional [catch effort monitoring] and novel approaches such as household and government statistical surveys), database management, data sharing, and reporting that
    - Reflect diversity of fisheries, fishing methods, ecosystem types and local cultural context, and enable intra- and cross-sectoral comparisons;
    - Include commercial, artisanal small scale, subsistence, and recreational fisheries; and
    - Include as far as possible the contribution of illegal, unreported, and unregulated fishing.
- Support the development of novel approaches to collect inland fishery data, e.g., remote sensing of habitat types and population densities linked to fish production models.
- Incorporate inland fisheries and aquaculture into ongoing agricultural statistical surveys to facilitate comparisons, and integrate information to support cross-sectoral decision-making.
- Increase support for efforts to improve capacity of fishery resource officers to collect information on the sector.
- Establish a minimum set of data requirements that would be practical for countries to collect and that would allow cross-sectoral comparisons.

Step 2: Correctly Value Inland Aquatic Ecosystems

The true economic and social values of healthy, productive inland aquatic ecosystems are often overlooked, underestimated and not taken into account in decision-making related to land and water use. Economic and social assessment is often difficult and valuation often limited. In most cases, especially in the developing world, inland fisheries are part of the informal or local economy, so their economic impact is not accurately measured in official government statistics.

Implementation recommendations

- Apply the principles of the Voluntary Guidelines for "Securing Sustainable Small-scale Fish eries" in inland fisheries and in so doing, recognize, respect, and support governance rooted in traditional customs, rights, and ecological knowledge.

[1] Food and Agriculture Organization of the United Nations and Michigan State University. 2016. The Rome declaration: 10 steps to responsible inland fisheries. Food and Agriculture Organization of the United Nations, Rome and Michigan State University, East Lansing.

- Promote and support the adoption of approaches that include assessment of the ecosystem services provided by inland aquatic ecosystems to value their contribution to ecosystem health and societal wellbeing.
- Ecosystem services should be valued along the entire value chain.

Step 3: Promote the Nutritional Value of Inland Fisheries

The relative contribution of inland fisheries to food security and nutrition is higher in poor food-insecure regions of the world than in many developed countries that have alternate sources of food. Good nutrition is especially critical in early childhood development (i.e., the first 1,000 days). Loss of inland fishery production will undermine food security, especially in children, in these areas and put further pressure on other food producing sectors.

Implementation recommendations

- Maintain or improve the accessibility/availability of nutrient-rich fish in areas with traditionally high fish consumption and/or high levels of under-nourishment and malnourishment by ensuring fair and equitable access regimes.
- Establish fishery and water management plans that include maintenance of an adequate and diverse supply of nutrient rich aquatic products.

Step 4: Develop and Improve Science-Based Approaches to Fishery Management

Many inland waterbodies do not have fishery or resource management arrangements that can adequately address sustainable use of resources. Where management arrangements exist, compliance and enforcement are often minimal or non-existent. This may result in excessive fishing pressure, decreased catch per unit effort, and conflicts between fishers, as well as changes in the productivity of fishery resources. In some areas, reductions in fishing capacity will be required. To facilitate fishery management, it will be important to improve access to and promote better sharing of data and information about inland fisheries supporting the assessment–management cycle.

Implementation recommendations

- Implement an Ecosystem Approach to Inland Fisheries.
- Support effective governmental, communal/co-operative, or rights-based governance arrangements and improve compliance with fishery management regulations.
- Modify or establish fishery and resource management arrangements to protect the productive capacity of inland waters and the livelihoods of communities dependent on the resource.
- Where reducing fishing capacity is called for, establish appropriate social safeguards and provision of alternative livelihoods for people leaving the fishery sector.

Step 5: Improve Communication among Freshwater Users

Information on the importance of the inland fishery and aquaculture sectors is often not shared with or accessed by policy-makers, stakeholders and the general public, thereby making it difficult to generate political will to protect inland fishery resources and the people that depend on them. Moreover, many misconceptions exist on the needs and desires of fishing communities.

Implementation recommendations

- Building from the “Small-Scale Fisheries Guidelines” and other relevant instruments, use ap propriate and accessible communication channels to disseminate information about inland

fish, fishers and fisheries to raise awareness of inland fisheries' values and issues, to alter human behavior, and influence relevant policy and management.
- The fisheries sector should engage other users of freshwater resources and participate in national and international fora that address freshwater resource issues, conflicts and synergies.
- The fisheries sector should invite other users of freshwaters to participate in fisheries fora.

Step 6: Improve Governance, Especially for Shared Waterbodies

Many national, international and transboundary inland waterbodies do not have a governance structure that holistically addresses the use and development of the water and its fishery resources. This often results in decisions made in one area adversely affecting aquatic resources, food security, and livelihoods in another.

Implementation recommendations

- Establish governance institutions (e.g., river or lake basin authorities) or expand and strengthen the mandate and capacity of existing institutions to address inland fisheries needs in the decision making processes.
- Commit to incorporating internationally agreed decisions on shared water bodies within national government policies.

Step 7: Develop Collaborative Approaches to Cross-Sectoral Integration in Development Agendas

Water-resource development and management discussions very often marginalize or overlook inland fisheries. Therefore, trade-offs between economically and socially important water-resource sectors and ecosystem services from inland water systems often ignore inland fisheries and fishers. Development goals based on common needs, e.g., clean water and flood control, can yield mutually beneficial outcomes across water-resource sectors.

Implementation recommendations

- Promote cross-sectoral discussions about the trade-offs and synergies of inland water development and management options that consider the inland fishery sector a partner in resource development in an equitable manner.
- Identify and strengthen platforms and legal frameworks for multistakeholder-based decision-making and management.
- Incorporate inland fish and fisheries into the post-2015 sustainabilitydevelopment goals on water issues and include all ecosystem services provided by inland aquatic ecosystems.

Step 8: Respect Equity and Rights of Stakeholders

Lack of recognition of the cultural values, beliefs, knowledge, social organization, and diverse livelihood practices of indigenous people, inland fishers, fishworkers, and their communities has often resulted in policies that exclude these groups and increase their vulnerability to changes affecting their fisheries. This exclusion deprives these groups of important sources of food as well as cultural and economic connections to inland aquatic ecosystems.

Implementation recommendations

- Protect the cultural heritage of indigenous people and their connections to the environment.
- Ratify and implement the Indigenous and Tribal Peoples Convention of 1989 (ILO-160, as

well as the Universal Declaration of Indigenous Peoples and other International human rights instruments.

Step 9: Make Aquaculture an Important Ally

Aquaculture is the fastest-growing food production sector and an important component in many poverty alleviation and food security programmes. It can complement capture fisheries, e.g., through stocking programmes, by providing alternative livelihoods for fishers leaving the capture fisheries sector, and by providing alternative food resources. It can also negatively affect capture fisheries, e.g., introduction of invasive species and diseases, through competition for water resources, pollution, and access restrictions to traditional fishing grounds.

Implementation recommendations

- Adopt an ecosystem approach to fisheries and aquaculture management10.
- Recognize the common need for healthy and productive aquatic ecosystems and promote synergies and manage tradeoffs among fisheries, stock enhancement, and aquaculture.
- Regulate and manage the use of non-native species in aquaculture development.

Step 10: Develop an Action Plan for Global Inland Fisheries

Without immediate action, the food security, livelihoods and societal wellbeing currently provided by healthy inland aquatic ecosystems will be jeopardized, risking social, economic, and political conflict and injustice.

Implementation recommendations

- Develop an action plan based on the above steps to ensure the sustainability and responsible use of inland fisheries and aquatic resources for future generations.
- The action plan should involve the international community, governments, Civil Society Organizations, indigenous peoples groups, and private industry, and include all sectors using freshwater aquatic resources.

Inland Fish and Fisheries: A Call to Action

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Inland fish and fisheries provide food security, livelihoods, cultural and religious identity, recreation, and a source of income for millions of people globally (Welcomme et al. 2010; Lynch et al. 2016, this volume). Human connections to fish and fishing have existed for millennia on inland waters systems as diverse as the Mekong River (Voeun 2004) to the glacial lakes of the northern United States (Bogue 2000). Given the long-term importance of inland fisheries to societies, the lack of attention given to maintaining their sustainability during development of management policies and allocation decisions for inland water resources is alarming yet all too common. Further, globally, even the most basic information about inland fisheries is generally lacking, such as basic life history of important food fishes, total harvest and production, total contribution to employment and livelihoods,

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and contribution of inland fish to nutrition and human well-being (Welcomme et al. 2010; Beard et al. 2011). When in-depth analyses are attempted, the numbers reported often underestimate the true contribution of inland fisheries to society (Baran et al. 2007; Hortle 2007; Bartley et al. 2015). Increased pressure on inland waters to support multiple uses, such as the proposed damming of the Mekong River system for hydropower (Ziv et al. 2012), the diversion of water for municipal and agriculture use in California (Tanaka et al. 2006), and the conversion of forests to agriculture in the Amazon basin (Davidson et al. 2012), creates numerous challenges for inland fisheries management. The development of improved and integrated approaches (e.g., integrated water resources management; Hooper 2003; Grigg 2008) to understand the important role of inland fisheries to society and provide better governance mechanisms that cross political and sectoral boundaries will be important to ensure inland fisheries sustainability.

Inland fisheries are defined by Welcomme et al. (2010) to include the exploitation of fish from waters inland of the coastline. Inland fisheries range from the small-scale, local artisanal fisheries that are commonly found in the developing nations to the high-technology and recreational fisheries commonly found in the industrialized nations (Welcomme et al. 2010). The geographic scale of inland fisheries can range from small ponds and reservoirs to the world's largest rivers and lake systems. Threats to inland fisheries include unsustainable harvest (Allan et al. 2005; Post et al. 2002), but unlike large-scale, marine commercial fisheries, the majority of threats are external to the fisheries sector and threaten the broader integrity of the hydroecological systems that sustain fisheries (Cooke et al. 2014). Inland waters are impacted and threatened by multiple activities, including the development of hydroelectric power, agriculture and irrigation, municipal water use, mining and other resource extraction processes, navigation, and the modification of riparian corridors to support human activity (Dudgeon et al. 2006; Vörösmarty et al. 2010; Beard et al. 2011). Consequently, the development and implementation of policies and strategies for the management of inland waters that do not consider all freshwater-based sectors are often detrimental to fish and fisheries. With a lack of reliable data about the status of fish populations, harvest, and the economic value of inland fisheries, it is often difficult for inland fishery managers to engage effectively in the decisions about water use (Beard et al. 2011). If inland fisheries are to be sustainable into the future, the engagement of policymakers and decision makers across all sectors reliant on freshwater will be necessary.

Given the need to develop sustainable approaches to inland fisheries management, bringing together a cross-sectoral community to identify and discuss issues specific to inland waters is important to engage and incorporate fisheries in water resource management decisions. To build this cross-sectoral community, the Food and Agriculture Organization of the United Nations (FAO) partnered with Michigan State University (MSU) to bring those working on global inland fisheries together with stakeholders from other inland water sectors for a global conference on inland fisheries titled Freshwater, Fish and the Future: Cross-Sectoral Approaches to Sustain Livelihoods, Food Security, and Aquatic Ecosystems. The ultimate goal of this conference was to identify science and management challenges to assure that inland fisheries become part of the decision-making framework regarding use of inland water. In January 2015, 205 scientists, managers, and others from 48 countries representing the global community interested in inland fisheries and the inland water sector met in Rome at FAO headquarters. The conference, sponsored by MSU and FAO, was structured to ensure global representation and interaction between the sectors reliant on freshwater by uniting participants among four thematic panels: biological assessment, social and economic assessment, drivers and synergies, and policy and governance. This partnership facilitated global cross-sectoral discussion about the status and value of inland fisheries. The outcomes of this discussion were to identify the science, management, and governance challenges to assure that inland fisheries become part of the inland waters decision-making framework.

The biological assessment thematic panel (see papers in Biological Assessment Theme) focused on identifying traditional and novel approaches and methods that could improve biological production assessment, that are scalable and effective, and that are feasible for implementation in both developed and developing nations. Furthermore, a variety of biological assessment tools that are flexible and robust need to be developed and validated for gathering and analyzing the needed data. For example, are there novel approaches that can be developed, such as remote-sensing-based approaches for estimating inland water productivity and fisheries harvest? Given that aquatic habitats are the foundation of healthy and productive fisheries, it may also be informative to develop proxies for productivity based on environmental metrics. Additionally, what are the best ways to track fisheries harvest in the recreational, commercial, and subsistence fishery sectors? Is there a meaningful role for household surveys or fisher log books to assist in providing some of the missing and essential data? Do the same assessment techniques that work in rivers work in lakes? Is it possible to standardize the minimum set of information collected to allow for comparison across jurisdictions and inform broader comparisons? To be truly effective, however, assessment information about fish and fisheries must be informative in fishery and other sectors' planning and decision making.

The social and economic assessment thematic panel focused on improving understanding of the economic and societal value of inland fisheries. The goal of this panel (see papers in Economic and Social Assessment Theme) was to explore and develop new approaches to determine the monetary and nonmonetary value of freshwater fisheries, including their importance to human health and nutrition, personal well-being, and societal prosperity. Better assessing and conveying the value of fisheries is expected to elevate understanding about the role of inland fisheries in individual well-being and societal prosperity and stability. The increased understanding of the value of these fisheries will help provide a common metric for evaluating alternative uses of these resources and habitats. The panel focused the discussion on developing methods that would value inland fisheries appropriately, using either traditional market-based approaches or nonmarket-based alternatives. Additionally, the panel explored the important role of fish in nutrition and emphasized a need to better incorporate this role into discussions about inland fisheries. Finally, the panel investigated methods and approaches to integrate and respect the rights of stakeholders, ensure that gender-equity considerations are included in policy and management decisions on water and fisheries governance, and ensure that water allocation discussions incorporate the frequently disenfranchised local community, many of whom are involved in fishing-related activities on a part-time or occasional basis and are thus overlooked even in programs targeted directly at those involved in the fisheries.

The drivers and synergies thematic panel (see papers in Drivers and Synergies Theme) focused on the identification of multiple sectors relying on inland waters, such as industrial and human use, tourism, recreation, navigation, hydropower, and irrigation and how use of inland waters by these sectors can either influence the sustainability or be synergistic with inland fisheries. To ensure long-term sustainability of inland fisheries, the management of sustainable freshwater systems requires making informed choices emphasizing those services that will provide sustainable benefits for humans while maintaining well-functioning ecological systems. Given that many sectors reliant on inland waters focus on a singular service and operate independently with no consideration of other inland water sector operations, the development of meaningful communication opportunities and approaches across sectors that emphasize a common language, valuation scheme, and understanding will help ensure that trade-offs are properly incorporated in final decisions about water allocation. A creation of approaches that allow the development of goals based on common needs, such as improved water quality, can lead to mutually beneficial outcomes across water-use sectors.

The inclusion of all sectors relying on freshwater in governance and management frameworks, and in decision-making processes influencing freshwater use and allocation, should help ensure informed decision making.

The policy and governance thematic panel (see papers in Policy and Governance Theme) focused on the identification of approaches and methods to ensure that inland fisheries are fully integrated into freshwater decision-making frameworks. Approaches that link inland fisheries management goals and science directly with the needs of policymakers will assist strategic decision making in better understanding the costs and benefits of their decisions, inform adaptive management, enhance environmental justice, and result in enhanced enforceable regulations for more sustainable management of inland fisheries. Given that inland waters are interconnected and cross multiple political boundaries, using approaches that encourage cross-boundary discussions about the use of inland waters and its impact on fisheries production is important to avoid negative consequences to the food security of people that are distant from where the water is used for other human uses. To this end, there is a need to better understand the opportunities and constraints to cross-sectoral and cross-jurisdictional governance approaches and development of methods to assure that governance decisions take into account the contribution inland fisheries make to food security, human well-being, and ecosystem productivity at the local, regional, national, and global levels.

Modification of the world's waterways has occurred for millennia, with well-documented impacts on fish and fisheries and the impact on food security of local people. In almost all instances, these modifications were made with little knowledge or regard to the impacts to not only the fish and fishery, but also the people who rely on them (Lynch et al. 2016). With some of the globe's most food-insecure human populations dependent on inland fisheries for nutrition and livelihoods (Smith et al. 2005), coupled with the cultural attachment of many of the world's people to fisheries (e.g., indigenous peoples, recreational anglers), development of more holistic approaches to ensure the sustainability of inland waters, fish, and fisheries is necessary.

During this conference, the global inland fishery community identified multiple needs and science gaps that must be addressed if there is any hope of rehabilitating, maintaining, or enhancing inland fisheries. A conference, however well organized and attended, does not necessarily lead to action. Investment in the science and management approaches will be necessary to advance understanding of the critical role of inland fisheries to sustain inland fisheries for future generations. With the current threats and modifications to some of the world's greatest rivers and the resultant impacts projected to their inland fish and fisheries, understanding and conveying the critical role of these fisheries to human society and food security is essential to avoid future losses. The global inland fisheries community and their partners should continue the discussion at the appropriate venues and ensure that the critical roles inland fisheries play are highlighted during discussions about the food–water–energy nexus. Strikingly, inland fisheries were notably absent in the recent revision of the United Nation's sustainable development goals (no mention under the water goal or the marine fisheries goal; https://sustainabledevelopment.un.org/?menu = 1300).

This book is organized to reflect the format of the global conference. The Plenary Talks section presents the talks that were given during the plenary sessions of the conference. This section is followed by four sections mirroring the four conference themes: biological assessment, economic and social assessment, drivers and synergies, and policy and governance. Each of these themes begins with a review paper that summarizes the background information and the challenges associated with the theme and explores the topics that informed the recommendations developed from the conference. A number of key scientific papers and case studies relevant to each theme are also included. The Conclusion summarizes the key recommendations arising from the global conference, called "The Rome Declaration: Ten Steps to Responsible Inland Fisheries," and details a call for action.

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Inland Fisheries: Past, Present, and Future

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This address is intended to set a background to the conference on freshwater, fish, and the future by examining the nature of inland fisheries and how we reached our present state of knowledge and offering possible directions for the future.

In 2012, records submitted to the Food and Agriculture Organization of the United Nations (FAO) by member countries show that inland fish catches reached 11,630,680 metric tons after a more or less linear growth of 3.6% per year since 1950. Most of this catch came from Asia (68%); 23% came from Africa, and the rest from the other continents. Even within the various continents, yields were very strongly distributed by country. For instance in Asia, 90% of the catch came from only eight countries, whereas in Africa, 18 countries contributed 90% of the catch (Welcomme 2011). Nevertheless, inland fisheries continue to play an important role in the livelihoods and food security of large numbers of people in all countries of the world. For example, it has been estimated that more than 56 million people were directly involved in inland fisheries in the developing world in 2009 (BNP 2009). Participation by recreational fishers is more difficult to assess, but recreational fisheries have been estimated to involve 118 million people in North America, Europe, and Oceania (Arlinghaus et al. 2015) and be worth £1 × 10^9 in UK household incomes for 37,000 household jobs (Mawle and Peirson 2009), €25 × 10^9 in Europe (European Anglers Alliance and European Fishing Tackle Trade Association, presentation in the European Parliament 25 March 2004), Can$8.3 × 10^9 in Canada (Fisheries and Oceans Canada 2010), and US$34 × 10^9/year expenditures, retail sales, and license fees (U.S. Fish & Wildlife Service 2011). In addition, the fishery for ornamental species was valued at US$1.5 × 10^9 for both marine and inland species in 1998.

In the beginning, fishing must have been relatively simple. Inland fisheries have been a significant source of food from very early on in history, as attested by the variety of hooks, harpoons, and fish remains that shows up regularly in prehistoric sites. Many early river-based civilizations show fishing as a major activity, and traditional controls on the fishery are probably as old as fishing itself. More formally, China had fisheries regulation as early as the beginning of Western Zhou Dynasty (about 11th century B.C.) when the emperor listed protection of fishery resources as an important national policy (Qiu 1982). In Europe, the increased pressure on fishing through the ages has been reflected in a series of edicts that limited effort. As early as Etruscan times, a bas-relief of a sturgeon was mounted on the walls of the fish landing sites in Rome, allegedly to indicate the minimum size for sale. In England, in 1,000 A.D., Aelfric (Watkins, no date) writes of the fisherman who reported catching "eels, pike, minnows and dace, trout, lamprey and any other species that swim in the rivers, like sprats." He stated that he cannot catch as much as he could sell in the town and shows a great reluctance to go to the sea to fish. Indeed, at this time, Edward the Confessor was obliged to issue an edict for the removal of fish weirs in the Thames and its tributaries as they were hindering river transport. Somewhat later, King Henry the First died, reputedly of a surfeit of lampreys, showing the importance of fish in

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court life. Measures to control fisheries in the Thames even appeared in early versions of the Magna Carta. In the 1600s, Colbert, minister to Louis IV of France, was obliged to regulate the minimum sizes of fish being caught in the Loire and the Seine because of the intensity of demand.

These attempts at legislation demonstrate an early appreciation of the impacts of heavy fishing on fish stocks, and until relatively recently, knowledge did not advance much beyond that. Systematic investigations of inland fisheries began in North America and Europe towards the end of the 19th century, when sporting interest in salmonids, mainly Atlantic Salmon *Salmo salar* and trouts, caused a surge in studies on the behavior of the species and development of techniques for stocking and improvement of their habitats. At about that time too, interest in the fisheries of the lower Danube (Antipa 1910), the Rhine (Lauterborn 1918), and the Illinois River (Richardson 1921) were expressed in publications that were precursors of work yet to come. For example, Antipa's seminal work on the floodplain fisheries of the lower Danube in Romania already described many of the features of floodplain fisheries that were to be verified in the 1970s.

The deteriorating condition of northern temperate inland waters increasingly caused concern following the industrial revolution. So poor was the condition of many rivers that they were judged to be fishless in the 1950s. In response, some government legislation regulating inland fisheries began to be introduced in the mid-19th century. A number of institutes were founded to study the processes regulating inland fish and fisheries—the Research Institute of Fish Culture and Hydrobiology (Czech Republic) and the Department of Fisheries and Oceans (Canada) in 1921, the Freshwater Biological Association in 1929, the University of Michigan in 1930, the Central Inland Fisheries Research Institute (India) in 1947, the Istituto Nacional de Pesquisas Amazonicas (Brazil) in 1952, the Inland Fisheries Institute in Olstyn (Poland) in 1951, and the Instituto Nacional de Limnologia (Argentina) in 1962.

The expansion of European populations into the tropics from the mid-1800s onwards sparked a growing interest in the fauna and flora of these regions. The fascination with strange and exotic life forms accompanied the early explorers and a series of museums appeared across Europe and North America to deal with the wealth of material arriving from Africa, Asia, and Latin America. The Musée National in Paris, The Natural History Museum in London, the Royal Museum for Central Africa at Tervuren, and the Smithsonian Institute in the United States all amassed large collections of type specimens described by a series of noted taxonomists, including Boulenger, Valenciennes, Geoffrey Saint-Hillaire, and Richardson in the late 1800s, a trend that persisted until the late 1960s with workers such as Daget, Greenwood, Whitehead, and Trewavas. This phase tended to be purely descriptive of species with little attention being paid to their behavior, biology, or ecology. New species continue to be found and described, especially from the larger tropical systems, and the importance of correctly identifying the animals forming part of our fisheries has not diminished with time. Unfortunately, taxonomy is unfashionable now, the major museums have been transformed into houses of entertainment, and there is a sad lack of competent taxonomists.

The earliest systematic study of a tropical inland fishery was carried out on Lake Victoria in the 1920s. The fishery for Singidia Tilapia *Tilapia* (now *Oreochromis*) *esculentus* was growing fast in the north of the lake, and the mean sizes of fish caught were dropping. Michael Graham (1929) investigated the causes for this and, by applying the emerging discipline of marine stock assessment, concluded that the stocks were overfished. He also recommended the establishment of a research institute for the East African Great Lakes. This recommendation was endorsed by Barton Worthington following his 1936 visit to the East African Great Lakes (Worthington and Ricardo 1936). As a result, the Joint Fisheries Research Organisation was founded in what is now Malawi and Zambia in 1950, followed by the East African Freshwater Fisheries Research Organization, Jinja, Uganda, in 1947. The Belgians had also founded a research institute at Uvira on Lake Tanganyika, and the

French on the Niger River at Mopti, Mali at about the same time.

The concentration on limnology through these early research years resulted in an increased understanding of the functioning of lakes summarized by Hutchinson (1957) in *A Treatise on Limnology*, and this drew attention to the processes of eutrophication that soon came to assume significance as one of the main human impacts on lacustrine systems. Little was known as to the functioning of large rivers at this time. Indeed, these were not considered appropriate for detailed research due to the great difficulties with sampling and the opinion that each river was different and generalization impossible. At this time, too, river channels and river lakes were thought to be distinct, mainly due to the highly modified nature of most temperate systems and the lack of knowledge of tropical systems.

The tools available for research were still primitive or lacking (slide rules and hand-operated calculators were still the order of the day), statistics had yet to emerge as a dominant force in the interpretation of data, and communication with libraries and other academics was slow and unreliable. As a result, most studies were purely descriptive natural history. The north temperate countries had mainly concentrated on salmonids and the increasingly apparent problems with water pollution and recreational fisheries. In the tropics, awareness was emerging about the importance of inland waters for the provision of food. As a consequence, research and management developed very differently in the temperate countries and the tropics. In the temperate zones, the focus of research and management was increasingly on water quality. Rivers and lakes in the developed world had been highly modified by the 1970s, leaving little of the original structure and trophic state. Fishing for food had generally declined, although Eastern Europe continued to have some important food fisheries. Furthermore, large-scale changes in the nature of aquatic systems were taking place elsewhere. The world was about to embark on two decades of concentrated dam building with a proliferation of reservoirs and modification of the structure and flood regimes of the rivers below them. Fish faunas, too, were being modified with major transfers of useful species around the globe for recreation, aquaculture, and, in some cases, capture fisheries.

Through the 1960s and 1970s, international interest centered on the development and management of the fisheries of the newly independent countries and their equally newly created water bodies. Research was conducted on broad aspects of fish biology, on the succession of species as reservoirs matured and on the behavior of fish in rivers. A series of externally funded international and bilateral projects focused on fisheries, fish biology, and ecology. These included both management-oriented activities and academic exercises, such as the International Biological Programme, which led to the creation of increasing numbers of national institutes. These were not confined to Africa, as internationally and nationally funded research was also developing rapidly in Argentina, Brazil, and Colombia. Such research is continuing and remains the major topic for published work on inland fish and fisheries, to date. It is questionable whether the continuation of basic biological studies is always the best use of research funds, but it must be recognized that much of this research is carried out as part of postgraduate studies and, as such, leads to a growing awareness of the importance of inland aquatic systems in the coming generations of scientists and administrators. The considerable body of work that has emerged has resulted in detailed knowledge of fish reproduction, migration, larval drift, feeding, and growth of some species in some systems and an understanding of the functioning of some aquatic ecosystems. By extrapolation, this has created a generalized knowledge base sufficient for the formulation of conservation and management programs.

Statistical tools such as frame survey methodologies and improved sampling and analysis techniques were also developed and expanded. A number of United Nations-funded projects executed through FAO investigated the various reservoirs and some lakes, mainly in Africa, predicting the possible yield and tracking the evolution of the fisheries. For example, simple predictive indices, such as the morphoedaphic index were then derived to help plan the future fisheries of the new reservoirs and dams. This work led to a growing appreciation of the fisheries of tropical systems as synthesized by Rosemary Lowe-McConnell (1975) and exemplified in a number of books and review articles on individual systems (see, for example, Sioli 1984 and Bonetto 1986). There was also a concerted effort at training personnel from the individual countries to intensify national capacity to carry out research and data collection, and the foundations of fisheries research institutes in many newly independent nations date from these times.

The possibilities also opened up for collaboration between the individual countries through FAO working with international institutions such as the European Inland Fisheries Advisory Commission, the Committee for Inland Fisheries of Africa, the Indo-Pacific Fisheries Council, and the Comision para la Pesca Continental Latino Americano whose various working parties, seminars, and symposia gathered and interpreted the data that were being generated.

A marriage of temperate zone experience and data gathered from modified aquatic ecosystems and data from the relatively unspoiled systems of the tropics produced a series of models of ecosystem function. At this time, descriptions of flow-regulated river floodplain systems emerged based on synthesis of the various projects by Lowe-McConnell (1975) and Welcomme (1979). These considered rivers as integrated channel–floodplain systems—a concept long inherent in the French terminology of "lit mineur" and "lit majeur." There were a series of major international symposia, including a highly significant meeting in Seattle in 1980 and the seminal large river symposium of 1986 (Dodge 1989), which led to generalized theories of river function such as the river continuum concept (Vannote et al. 1980.) and the flood pulse concept (Junk et al. 1985). A second large rivers symposium was held in Pnom Penh, Cambodia in 2003 (Welcomme and Petr 2004). The corollary to the improved productivity with increasing area of floodplain flooded was extended to fish catch, where strong relationships between flooded area and the amount of catch in the same or following years emerged in many systems. This linkage between fish productivity and flow regime in rivers has since been extended to river-driven lakes and reservoirs.

During the 1970s and 1980s, evidence was accruing of the failure of simple stock dynamic models in predicting the productivity of multispecies fisheries and the response to fishing of the individual species. Some attempts in rivers and lakes had been made to assess stocks of individual species, but it became apparent that the multispecies, multigear fisheries of the tropics did not conform to the concepts of maximum sustainable yield then being applied to marine fisheries. Although such calculations might be valid for individual species, particularly in the more stable environments of lakes, the responses of multispecies (and multigear) fish assemblages to increasing fishing pressure were the progressive disappearance of the larger species from the fishery and their substitution by successively smaller species—a process later named the "fishing-down" process.

Fishing-down, which in inland waters is not linked to trophic level as some marine theorists propose, is strictly linked to species length and has continued to this day when many Southeast Asian, South Asian, and African fisheries are based on only the smallest species and the 0 and 0+ year-classes. It is assumed that the increasing numbers of fishers in many inland waters is driving the increase in effort. The increasing numbers of taxa recorded from inland fisheries in most regions of the world since the 1950s is consistent with the predictions of the fishing-down model, although it might also be explained by better identification and reporting at the taxonomic level.

The wealth of data from the various projects and working parties of the international fishery bodies enabled relationships such as the number of species per basin area to be established for various continents and the yield from rivers estimated as a function of basin area and river channel length. Relationships and models were also developed that showed the dependency of catches in rivers on the extent and duration of flooding. These explained the considerable year-to-year variations in river catch and indicated the extent of losses that occur when flood regimes in rivers are modified by damming, floodplain drainage, and water abstractions (see Welcomme 2001 for review).

Similar relationships were also derived for lakes and reservoirs, but these were far more complex as yields per unit area are strongly conditioned by a number of other factors such as lake depth, richness of the water (conductivity/total dissolved solids), and size of the water body. These show that small water bodies are generally much more productive, not least because they are much more responsive to heavy stocking. The enhancement of yield by stocking small natural and artificial water bodies has become a standard management tool throughout much of the tropical world. However, this is often pursued uncritically, and it is difficult to quantify the cost effectiveness of many individual fisheries.

By the 1980s, attention was shifting from biological and ecological aspects of management to the social and economic implications of fisheries. Funding was increasingly withdrawn by donors from basic biology in favor of social and political institutions. This led to attempts at the valuation of the recreational fisheries in Europe and the documentation of the importance of inland fisheries in the livelihoods of poorer peoples in the tropics. At the same time, there was a growing realization of the general failure to manage inland fisheries using the centralized and authoritarian systems that were then widespread, and a trend to various forms of participatory management emerged. There has been increasing experimentation with forms of comanagement through collaboration between fishers and their communities, local and regional government agencies, and other stakeholders that have met with varying degrees of success and continue to evolve today. These systems often consist of a mix of traditional and newer forms of management whereby agreements are reached on access, catch quotas, permissible gears, and mesh sizes and persist today as the basis for management of the sector at the fishery level. However, while individual fisheries may well be best managed at the local level, many functions, such as research and national and international agreements, remain the domain of central governments and even international bodies such as river and lake basin organizations.

Research, to date, shows the inland fisheries sector to be highly diverse. The ecosystems and habitats themselves are divided into lakes, reservoirs, and rivers, each with a rich subset of environmental conditions. Fish faunas are extremely diverse, with larger lake and river systems containing many hundreds, and in some case thousands, of species of various size and habit. The fisheries that exploit the systems range from subsistence through commercial to recreational, each with its own rich variety of fishing gear and requirements for management. The objectives of exploitation are also variable ranging from basic provision of food through income, taxes by governments, recreational value, and conservation strategies, many of which may be in conflict. In addition to fisheries, there is a rapidly increasing pressure on the waters that support the fish for a range of other human purposes: power generation, irrigation, urban water supply, and industrial uses. Societies are thus dealing with a highly complex set of natural resources that needs equally diverse approaches to their management and conservation.

More recently, and for this reason, it has become increasingly apparent that much of inland fisheries management is subject to activities in economic sectors outside fisheries. For example, the intensive dam building of the latter half of the 20th century led to substantial modification of flow regimes and the nature and structure of downstream lakes and rivers. This trend has been reinforced by increasing abstraction of water for irrigated agriculture, which takes up to 70% of the flow of some rivers. Low flows also exacerbate the pollution and eutrophication of water bodies downstream. So far, several large lakes have disappeared due to these developments—the Sea of Azov being one and Lake Chad another, although in the latter case, the general drying out of the Sahelian area may also have played a role. Far from improving, this situation is deteriorating further as new dams are proposed for supposedly green power. The general impression is that each sector seeks to maximize its own financial and social yield without considering any impacts on other users. Indeed, it is extremely difficult for a diffuse social and economic system such as inland fisheries to compete financially or politically with prestigious mega-projects such as the gigantic dams now being proposed for the Mekong, Congo, and Amazon rivers. Furthermore, legal obligations may prohibit some sectors from maximizing their profits. Cross-sectorial planning, whereby the yields from all users are adjusted so as to maximize the total goods generated by any particular system, is extremely uncommon. The difficulty of finding such papers for submission to this conference is a case in point.

Cross-sectorial planning implies a growing emphasis on management of the landscape as a whole. In the case of fisheries, this ecosystem-based management has involved watershed or basin management planning at governmental and international levels in support of fisheries in both tropical and temperate countries. Planning at this level often depends on efforts to value the fisheries concerned using concepts such as ecosystem services. It also depends on a much more holistic understanding of processes at basin level using the ecosystems approach rather than the species- or habitat-centered approaches of earlier management strategies. This involves the careful conservation of the range of habitats required for successful completion of their life histories by the various guilds of fish inhabiting the system and the conservation of the migratory pathways between them. This level of management is based on the establishment of agreements on essential aspects of the aquatic environment, often involving allocation of water between the fishery and other users of the resource. One mechanism has been the setting up of conservation areas in some river basins to preserve essential aspects of the system, often through formal mechanisms such as Ramsar, which recognized fish as a conservation target in 1996. Adequate conservation of such areas often requires rehabilitation of already damaged systems to restore their form and function. Methodologies for channel and floodplain rehabilitation have been developed and are being applied, with particular attention being paid to alternative structures to facilitate fish passage through dammed rivers. Other preoccupations have been attempts to ensure that adequate water supplies are available for the fish assemblages by establishing agreed-upon environmental flows. These are aimed at protecting the aquatic environment from increasing abstractions of water for agriculture, industry, and human consumption, and control of flows for power generation is coupled with a more general concern on the impacts of dams. Research in support of river fish conservation now concentrates on major behaviors such as migration or larval drift, which are especially impacted by variations in flow. While environmental flow criteria have been developed and applied in many smaller temperate systems, the larger rivers of the tropics have proved more difficult. Here, the timing and magnitude of flows is crucial to the migration and reproduction of many species, and such events as failure to flood the floodplain at the right time of year may result in the loss of entire year classes of affected species. Equally important is the drive to maintain good quality water in rivers and lakes. The fishlessness of European rivers in the 1950s has been corrected by concerted efforts culminating in the European Water Framework Directive. Nevertheless, water quality continues to be poor in many other parts of the world, and mechanisms are needed to restore chemical health to affected systems for the health of both humans and aquatic organisms (International Decade for Action—Water for Life, www.un.org/waterforlifedecade/quality.shtml).

Unfortunately, the past 15 years have seen a lapse in attention to inland fisheries, particularly in the tropics, and a concentration on the rapidly growing aquaculture sector. Isolated centers, such as the Mekong River Commission, Lake Victoria Fisheries Organization, and the Institutes concerned with the Brazilian Amazon, have continued to do good work, further documenting the concepts developed in the 1980s. More generally, the withdrawal of funding from basic biological research in favor of human resources led to the inability of many countries to collect adequate data about their inland fisheries. The effects of lack of funding have accrued during a period of years, giving uncertainty as to the actual magnitude of the catch worldwide. Certainly, it is difficult to account for the continuing growth of inland fish catches since 1950. Is this a true increase? Is it based, as some would have it, on better fish statistics? Is it the result of data inflation for political reasons? Is it because of better technologies with stocking? Or is it some combination of these reasons? Furthermore, there are many intermediate technologies, ranging from wild capture fisheries through stocking, removal of predators, and fertilization of ponds to different degrees in the intensification of human control over the production of fish that make it very difficult to distinguish where inland capture becomes aquaculture. This continuum of practice leads to considerable confusion statistically, and many simple stocked fisheries are reported as aquaculture. For example, in Cuba, the not inconsiderable stocked reservoir catch was considered capture until a few years ago when it was reassigned to aquaculture. However, regardless of designation, stocked fisheries in natural water bodies are subject to the same environmental constraints as wild fisheries.

The growth of inland fisheries is especially difficult to explain in view of the threats from other sectors, especially increasing demand for water and environmental degradation. These adverse trends are likely to get worse as human population increases further and climate change destabilizes temperature and precipitation regimes. To some extent, negative pressures may have been counterbalanced by the increased productivity of fish assemblages as they are fished down. This means that there will possibly be an increasing loss of aquatic biodiversity as larger and more sensitive species are eliminated. There also appears to be an ongoing trend to meet rising demand for a limited resource by intensifying inland fisheries by stocking. This compensates for declining production from natural fisheries and increases control over harvests but favors a relatively narrow selection of species. Enhancement of fisheries involves substantial changes to the ownership and access patterns of previously public resources, a sort of new enclosures. Despite the lack of information about the cost effectiveness of such programs, it is to be anticipated that the trend to privatize many open fisheries will continue and even intensify in the future. As societies become more affluent, inland fisheries may progress from food fisheries to recreation and conservation, a trend that will continue as long as the recreational value outweighs the food value of catches.

It is clear that while imperfect and subject to further clarification by more research, the current knowledge of the biology and ecology of inland fish and fisheries is sufficient for us to manage fisheries in a sustainable manner and to propose solutions to conserve fisheries in the context of other users of water. This conference aims at focusing that knowledge to assess the role of inland fisheries in food security, identify better methods for managing the fisheries, and advise on better ways to integrate inland fisheries into the wider patterns of water use in river and lake basins. Whether resource managers will be able to apply such knowledge to grow the fishery sector further or indeed retain what still exists will depend on whether or not they can deal successfully with the challenges of increasing pressure on aquatic systems in general. It would be sad to have microwave ovens around the world with no fish to cook in them. Future trends may well depend on the development of integrated social, political, and economic institutions as world demand for food increases. Growth or decline will depend on political will by such institutions to sacrifice part of their possible individual benefit for the good of the whole, not only by the fisheries sector, but by all involved with the use of water.

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Water Governance and Management for Sustainable Development

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Why Water Governance?

As freshwater resources become increasingly scarce, so does competition for them. With consumption levels at a historical high, much of current economic development depends on reliable and safe access to water. The increasing cost of accessing water leads to tensions among different actors, requiring facilitated discussions between competing user groups, between economic sectors, and even between countries where freshwater resources span international boundaries. It has been acknowledged by the international community that water crises are, to a large extent, crises of governance rather than scarcity (FAO 2014c). Without governance, it is difficult to manage water resources, to strategize about investments in water-using sectors, to provide and maintain infrastructure, or to protect aquatic ecosystems adequately.

Water governance offers a framework for addressing issues of water scarcity that goes beyond water management. Water governance looks at processes, actors, and institutions that work across sectoral boundaries and with a broad range of users of water resources and services, including agriculture, food, energy, health, and environment. Governance encompasses the political, administrative, financial, and social domains of freshwater use, including formal and informal systems and mechanisms that impact the state, quality, and management of water resources. This multiscale approach is increasingly necessary as current management-only approaches often do not adequately address cross-cutting and interlinked issues. As we all rely on the same and limited resource base, no sector can operate rationally in isolation.

With increasing scarcity, it is key to rethink water governance. As current water management practices often operate in an almost silo-like environment, each sector manages its own intake and outtake with little communication with other water users. This can strain a system that is based on the hydrologic cycle—a continuous movement of water on, above, over, and under the surface of the planet. Withdrawals of water from this system are through interactions with only small parts of this cycle, in the form of rivers, lakes, seas, oceans, or underground aquifers, but these interactions can modify the cycle. Through structural and nonstructural semipermanent interactions with the water system, humans can change water flows through building physical infrastructure for storage and other flow regulation, which in turn can impact the entire cycle and the ability of all other water users to draw on the system.

Competition between freshwater uses

On a global scale, 70% of all withdrawn freshwater resources is used for agriculture, followed by industrial uses at 19% and the

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remainder for municipal uses (Comprehensive Assessment of Water Management in Agriculture 2007). This distribution varies from economy to economy and region to region. Differences can also be found between developed and developing countries, with developed countries such as the United States showing a much more diversified water withdrawal portfolio, with sectors like thermoelectric withdrawing at the highest rates, followed by irrigation (agriculture) at only 37% (Maupin et al. 2014). In comparison, developing countries can have irrigation withdrawals as high as 90%.

Freshwater withdrawals are not the only way humans' impact on water resources. Freshwater systems are increasingly affected by pollution as either the pollutants are discharged directly into water bodies or water is polluted during use and then discharged without or insufficient treatment. Most problems related to water quality are caused by intensive agriculture, industrial production, mining, and untreated urban runoff and wastewater (WWAP 2015). In the developing world, 90% of all wastewater is discharged untreated into water bodies (Corcoran et al. 2010). In industrialized countries, industry still dumps large amounts of pollutants and polluted waste into waters every year (WWAP 2015).

The flow regime changes and pollution both impact inland freshwater fisheries. Interactions with a water body influence the living organisms inside of it and this can result in changes to the ecosystem. While occasionally these changes can have positive effects on fish production in certain extensive culture systems (e.g., through nutrient enrichment), this is more of an exception than a rule. Increased sedimentation and intensified aquatic plant growth, as well as encroachment of agriculture into the margins, have negative consequences on ecosystems and fish.

Effects on aquatic environments

There are two main water-related issues facing aquatic ecosystems: (1) the health of aquatic ecosystems, and (2) the quantity and quality of surface and groundwater resources. Industrialization, urbanization, deforestation, mining, and agricultural land and water use often cause degradation of aquatic environments, which is the greatest threat to inland fish production. Water use in the form of withdrawals is having serious effects on lake levels, with a number of lakes in Asia having already reduced in size due to abstraction of water for agriculture and other uses. Expansion and intensification of crop production also affects inland fisheries negatively. Excessive loadings with urban, industrial, and agricultural wastes can have severe consequences for fisheries as lakes undergo eutrophication, increased sedimentation, and intensified aquatic plant growth and experience encroachment of agriculture into their margins, with consequent changes in their ecosystem.

Disputes over uses of water for irrigation and fisheries are often difficult to resolve due to different spatial and temporal water needs. This includes both quality and flow requirements for sustaining aquatic habitat. Increased aquaculture production may result in increased water use to maintain water quality.

The Need for Good Governance

Over the past two decades, the changes that impact water resources and, more broadly, natural resources have accelerated and surpassed developments of the previous 100 years. As the world's population is projected to move toward more than 9×10^9 by 2050, meeting the demand for food is to be planned well ahead of time in a manner that is in harmony with the ecosystems. The changing context is not only the population growth, which is a major driver of change for water resources, but also the changes in consumption patterns: the number of meals eaten per person, the content of meals, and the meal's manufacturing history. Processes have become more and more dependent on the use of natural resources, including water resources.

The Food and Agriculture Organization of the United Nations (FAO) is going through a strategic renewal in its policy making and implementation to move from a focus on improving sectoral management to creating governance systems that are conducive to implementing better, more comprehensive, and more inclusive management strategies. These new systems will tackle the linkages, boundary conditions, and interfaces between agriculture, water, and related key sectors and elements such as food, land, energy, natural resources, societal goals, and major drivers of change. This will be accomplished through addressing issues of access, rights, and tenure from the perspective of sustainability, inclusiveness, and efficiency. Typically, water governance in river basins is about the efficient, sustainable, and equitable allocation and use of water. This requires good knowledge and understanding of the resource and its use, the capacity to anticipate changes, and a dialogue-based, cross-sectoral, and inclusive process to give legitimacy to management decisions.

Examples of Food and Agriculture Organization of the United Nations Initiatives

Cross-sectoral dialogue in the Syr Darya basin

The dissolution of the Soviet Union resulted in the breakdown of the basinwide and integrated management system of the Syr Darya River basin (and, by extension, that of the whole Aral Sea basin) in central Asia. Prior to this, an agreement had been reached among the riparian countries to allocate water resources to both the upstream and downstream countries. This provisioned that upstream countries store water to provide it to the downstream countries in summer months for irrigation purposes. This, however, put a limit to upstream countries to release and produce hydropower during the winter months. Downstream countries, therefore, agreed to provide energy subsidies for their exported oil and gas to the upstream countries (UNECE 2015).

With the dissolution of the Soviet Union, downstream countries chose to sell their energy resources at full price on the international market rather than to continue subsidizing it for their relatively energy-poor upstream neighbors. The upstream countries responded by producing their own energy in form of hydropower, allowing the river to flow even in the winter months. In the end, floods and water shortages became more prevalent in downstream countries. This led to political tensions and issues that could not be resolved by focusing on agriculture or energy alone. The end result was a man-made disaster in form of the shrinking of the Aral Sea and the degradation of the basin's ecosystems and fish populations. As a result, fish stocks of economic importance either completely disappeared, or declined, and in some situations have been replaced by low-value fish. All of this has led to very negative impacts on livelihoods and people's health (UNECE 2015).

In 2012, the FAO organized a series of workshops in central Asia together with the Executive Committee of the International Fund for saving the Aral Sea (EC-IFAS) and the United Nations Regional Centre for Preventive Diplomacy in Central Asia (UNRCCA), using an innovative scenario-thinking approach. The goal of the workshops was to encourage a dialogue on the future development of the Aral Sea basin to which the Syr Darya is one of the tributaries. The scenario-thinking approach brings together a broad range of actors and sectors and fosters mutual understanding among the participants.

This process continued during the transboundary nexus assessment by the United Nations Economic Commission for Europe, the FAO, and the Global Water Partnership, highlighting once again that the solutions for the water sector also lie in the energy and agriculture sector. For instance, the agricultural sector can shift towards more water-efficient crops (than cotton) and invest in irrigation modernization and better land management schemes. The energy sector, which is of strategic importance to the economic development of countries with hydroelectric production potential, needs to take into account the associated problems with hydropower expansion for the river basin (FAO 2014b). This, however, requires dialogue to clarify options and the roles and responsibilities of different sectors.

Regional water scarcity initiative

The Near East and North Africa are among the most water-scarce regions in the world. These regions may be facing the most severe intensification of water scarcity in history over the coming years, with freshwater availability per capita expected to drop by up to 50% by 2050 while populations are growing and climate change is reducing freshwater access even further. Competition increases with increased scarcity, which requires facilitated debate between competitors, whether they are sectors, different user groups, or, in some cases, countries that share the same scarce water resources. While the regional water scarcity initiative (FAO 2014d) provides a good case study for how difficult it can be to get different sectors to talk to each other and to agree on a common way forward, it also shows that there are great benefits of going through this process as tradeoffs across sectors are identified and potential synergies are found.

Through a joint water scarcity initiative of FAO headquarters in Rome and the regional office in Near East and North Africa, FAO is helping the regional countries to more rationally manage their water resources. This is being achieved by establishing better policy formulation, cross-sectoral planning, a dialogue identifying synergies and putting these to use, and helping them to manage tradeoffs that exist between sectors and users.

The regional water scarcity initiative (FAO 2014d) started with a consultative process with countries and partners to develop a regional collaborative strategy on agriculture water management and a wide regional partnership to support its implementation. The strategy has seven focus areas:

1. Strategic planning and policies;
2. Strengthening/reforming governance at all levels;
3. Improving water management efficiency and productivity in major agricultural systems and in the food chain;
4. Managing the water supply through reuse and recycling of unconventional waters;
5. Climate change adaptation;
6. Building sustainability, with a focus on groundwater, pollution, and soil salinity; and
7. Benchmarking, monitoring, and reporting on water-use efficiency and productivity.

The regional water scarcity initiative (FAO 2014d) offers decision makers a platform to discuss the interlinkages between water and food security. This requires a clear understanding of the opportunities and trade-offs in managing water for agricultural production—in conjunction with other sectors.

Water tenure

While competition for water and other resources is growing, mechanisms to reflect values under scarcity and enhance efficiency of use are generally lacking. Farmers' water use rights are often informal and not protected by law or registered formally. In 2012, the Committee for Food Security endorsed the *Voluntary Guidelines on the Responsible Governance of Tenure of Land, Fisheries and Forests* (VGGT; FAO 2012). These provide a set of principles and practices that help countries establish laws and policies that better govern land, fisheries, and forests tenure rights. At the time of negotiating the VGGT, it was decided not to include water, on the understanding that the complexities of water management and the implications for the establishment of water tenure rights required further reflection. Water is referred to in the preface of the VGGT, where it is acknowledged that "the responsible governance of tenure of land, fisheries and forests is inextricably linked with access to and management of other natural resources, such as water and mineral resources."

Building on these voluntary guidelines, the concept of water tenure can be a useful tool to extend the debate beyond water rights and administration to understand linkages with land tenure, resource-use efficiency, and food security. The FAO plans to contribute to existing guidelines and more substantially incorporate the tenure issues into the water governance aspect more prominently and completely.

Irrigation governance

Worldwide, irrigated agriculture is promoted as a means to increase production and to provide better livelihoods for farmers. For this to happen, it is necessary to shift away from the business-as-usual approach and towards more forward-looking, participatory, and effective governance of the irrigation sector. Irrigation modernization plays a large role in promoting such a shift, adapting to changing user demands and varying biophysical and climate conditions.

The FAO's work on irrigation modernization aims to support countries in increasing water productivity in irrigated agriculture as a central solution to the water scarcity problem. Effective water governance requires an assessment of the costs and benefits of increasing water productivity for farmers' livelihoods, food security, economic returns, and potential water savings. The FAO provides, among other things, substantial advisory services to the member states in irrigated agriculture and governance of irrigation.

Most irrigation systems consist of water storage, major and distribution canals, and drainage canals. In particular, water storage is and will increasingly be an important means to enhance resilience to climate change (Tural et al. 2001). Per capita water storage capacity is still very low in many countries, particularly in Sub-Saharan Africa. In developing countries especially, there are many old irrigation systems that have been built for command of very large areas and are not efficient or even operational under the changing conditions. A lot of countries build artificial storage through structural measures such as dams and reservoirs, but the same objective can also be achieved through natural storage such as aquifers, soil moisture, and natural wetlands, depending on the specific circumstances. There is a range of storage options available: above and below the ground, small and large, serving different needs and different groups of people, behaving differently under climate change scenarios, and requiring different levels of investment and operation and maintenance (Renault et al. 2013).

Most importantly, these water storage options provide an opportunity for different water users to work together. There are opportunities to work with fisheries on natural wetlands or constructed wetlands in reservoirs. Generally, irrigation reservoirs have inherently unstable water levels that interfere with the basic biological functions of fish. There are also risks of water pollution through agricultural runoff. In many cases, indigenous fish stocks have declined.

A cross-sectoral perspective on reservoirs can help us identify management measures—such as the construction of wetland conditions in reservoirs—that will offer solutions for food production, fisheries, biodiversity, and much more. These constructed wetlands can hold water during dry seasons, creating smaller reservoirs that can create local fish ponds (FAO 2000). It shows that it is possible to look at ways of sustainable use making sure that different interests will be met now and in the future.

Governance of water for pollution control and water quality management

Water quality is another global challenge closely linked with crop and livestock production and fisheries. Water quality governance is a complex subject, often not existing at all or lacking in strength or fundamental requirements, making it prone to corruption. In partnerships with stakeholders, particularly United Nations Environment Programme (UNEP) and the World Health Organization, FAO's work on water quality governance is focused on the development of tools (e.g., tailored quality standards, treatment and recycling guidelines, environmental impact assessment, measurement, and monitoring,) and on strengthening regulations and institutional reforms for water quality management and pollution control.

One recent program is the governance of water quality in terms of pollution control and the health sector in the form of water borne diseases. The current implementation countries have been designated as Peru and Nepal. The program is designed to develop a multidisciplinary monitoring and reporting tool to measure and analyze the linkage of different water quality and food safety parameters and the epidemiology of diseases. This is important in a country like Nepal, which suffers from the dumping of waste in rivers, excessive use of pesticides and agrochemicals, and waterborne diseases such as intestinal worms and typhoid, and Peru, which faces major water quality challenges from mining, agriculture, and untreated wastewater.

The monitoring tool will look at

- where effluents of agriculture pollution cause disease in humans—for example, through drinking water or through accumulation in foods (e.g., heavy metals, pesticides, and fertilizer residues);
- where waterborne diseases from agricultural water use prevail; and
- where polluted water is used for irrigation to grow food.

As a result, we will be able to

- analyze the nature of hot spots,
- map the cause of the pollution and diseases outbreaks, and
- make wise investment decisions and take targeted action to mitigate and eliminate health risk factors.

Aquaculture—A Future Challenge

Asia has the greatest freshwater aquaculture production in relation to land area and water surface area. In Africa and Latin America, there is potential for growth of freshwater aquaculture production, but it is becoming more restricted due to urban development and high competition for land and water resources. Fish production in the coastal and offshore marine environment offers alternative and new opportunities for aquaculture and for the supply of world food fish when freshwater and land become scarcer (FAO 2014a).

In Conclusion: Cross-Sectoral Governance in Practice

The FAO will continue emphasizing the importance of water for food security and nutrition, as well as the sustainable management of natural resources for food and livelihoods in the international water debate at all relevant levels. This will be done through strategic partnerships with international institutions and stakeholder groups, and by taking advantage of prominent fora where key decisions are made or influenced. While there is still a lot more awareness needed for cross-sectoral work in sustainable food and agriculture and natural resource management, the knowledge base is expanding with more awareness and more demand on both sides from the civil society as well as the involved sectors. We now know a lot more about interactions and interlinkages, how decisions in one sector can impact another sector or the natural resource base at large. Analytical tools are more available now[1] and we have evidence of engagement across sectors, particularly the private sector where cross-sectoral implications especially involving the use of natural resources are much better understood through the economic and image-related impacts Flammini et al. 2013).

But there is still a lot of work to be done in the respective sectors. Policies to a large extent are still formulated in a compartmental manner, and national governments' work in planning and implementation is sometimes coordinated more vertically than across sectors. Policy formulation remains fragmented and not very conducive to cross-sectoral collaboration. While there is a common vision and perceived need for all parties to come together, government planning systems still remain in their sectoralized compartments. The FAO's new strategic framework is all about collaboration across sectors and we certainly hope to be able to have more concrete results of the collaboration between water and fisheries within FAO and beyond.

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Using Tribal Fishing Rights as Leverage to Restore Salmon Populations in the Columbia River Basin

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Introduction

The Columbia basin is on the West Coast of North America, draining into the Pacific Ocean. Approximately 85% of the basin lies within the United States, primarily in the states of Oregon, Washington, Idaho, and Montana, with the remainder in British Columbia, Canada. The river system is comprised of two major rivers: the Columbia and Snake. Columbia Lake and the adjoining Columbia Wetlands form the headwaters of the Columbia River in British Columbia. The headwaters of the Snake River are in Yellowstone National Park in Wyoming.

The Columbia River system is the lifeblood of all the tribes and First Nations found along its entire length. Since time immemorial, the water, salmon, game, roots, and berries of our homeland—the sacred first foods—have sustained our health, spirit, and cultures. So fundamental was this connection that when the Yakama, Umatilla, Warm Springs, and Nez Perce tribes entered into treaties with the United States in 1855, they specifically included language to ensure that they could continue to fish, hunt, and gather their first foods. (See the Columbia River Inter-Tribal Fish Commission's Web site, www.critfc.org, for the full text of each member tribe's 1855 treaty.) They understood that the connection of their people to these resources must be maintained if there was any hope in preserving their unique cultures and values. When they entered into these treaties, their primary concern was access to these plentiful natural resources. At the time of treaty signing, returning salmon populations were, on average, an estimated 17 million annually (NWPPC 1986), with returns in some years estimated to be as high as 34 million fish. They had no way of knowing that in less than 150 years, salmon would be facing the threat of extinction.

In their treaties, these four tribes ceded a collective 66,591 mi^2 (172,470 km^2) of their lands to the United States, agreeing to live on reservations. The current tribal reservation lands make up a small percentage of the tribes' traditional homelands (Figure 1). However, they all retained limited rights to these ceded lands, including reserving the right to fish, hunt, and gather at all their historical usual and accustomed areas.

Ecosystem Impacts in the Columbia Basin

Human impacts on the Columbia basin have dramatically altered the entire ecosystem since the signing of the treaties. Increased human population, dam construction, unregulated harvest, and substantial habitat modifications drastically reduced salmon populations. Annual salmon runs today average fewer than 2 million fish—about one-tenth of what they were, on average, historically (NWPPC 1986). Much of this decline occurred before major dam construction, which began in the 1930s and continued into the 1970s.

These dams destroyed salmon spawning grounds, created inhospitable water environments, and delayed salmon smolt out-migration. Many of these dams have fish ladders, allowing adult salmon to swim upstream to

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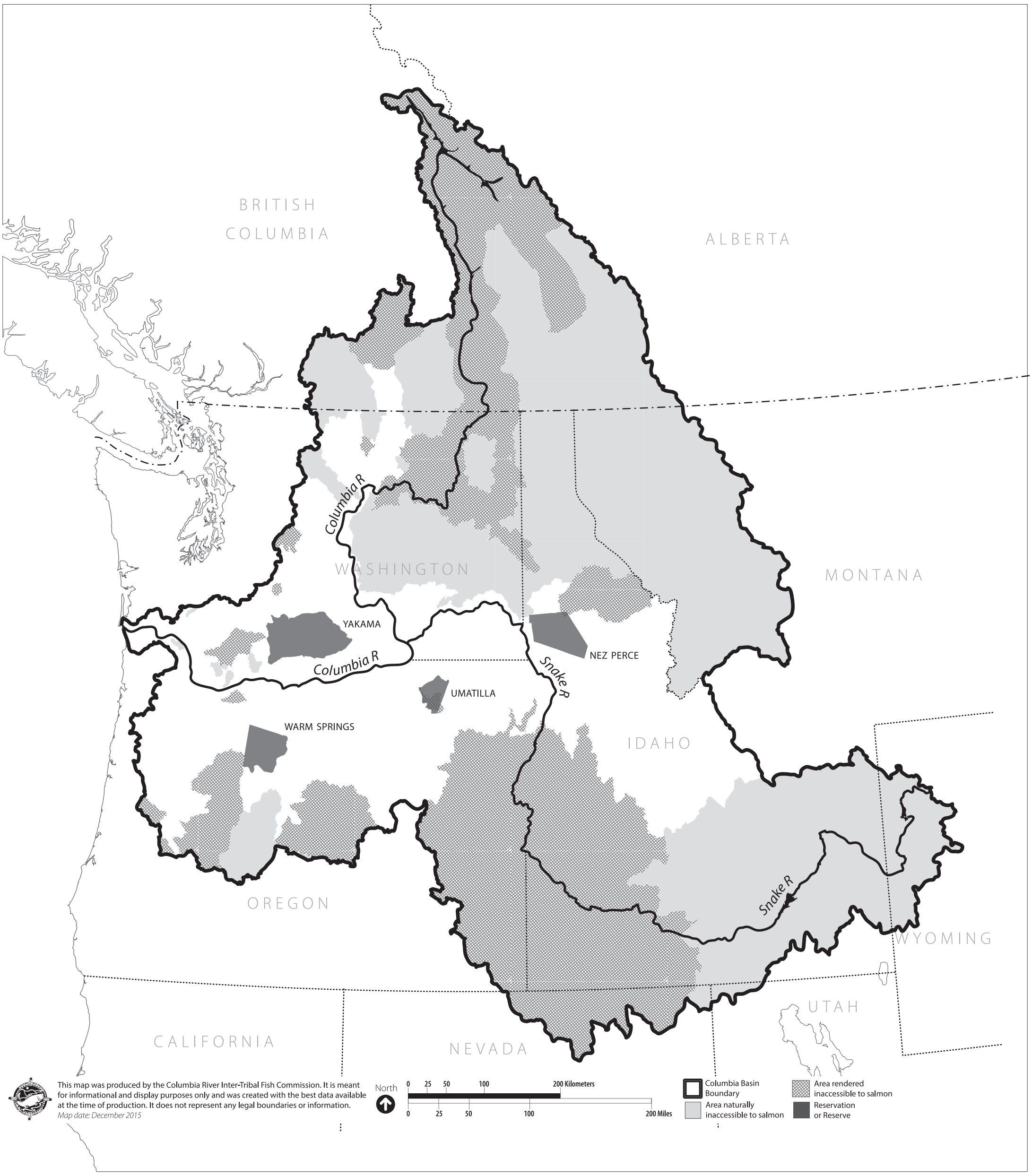

Figure 1.—The Columbia River basin. Areas historically inaccessible to anadromous fish due to natural passage blockages are indicated in light gray. Areas rendered inaccessible to anadromous fish due to human activity are indicated in dark gray.

spawning grounds, but several dams were constructed without these structures, preventing salmon, sturgeon, and lamprey from returning to large sections of the Columbia River basin. (See Figure 1 for areas rendered inaccessible to salmon due to hydropower development.)

The ecosystem is impacted by all of the dams in the region. However, two dams in particular dealt major blows to tribal culture. In 1940, the reservoir that rose behind Grand Coulee Dam flooded Kettle Falls, the site of a major upriver tribal fishery. This scenario was repeated on a grander scale in 1957 when The Dalles Dam was completed. Four and one-half hours after closing the floodgates on that dam, the magnificent Celilo Falls was silenced and what was once the largest salmon fishery in North America was erased, taking with it the significant tribal trading center based on a salmon economy that had developed at this location. For many tribal elders, this loss is still an unhealed wound to their hearts and spirits. The tribes remain hopeful that one day these dams will be removed and the roar of these majestic falls will echo once more.

Exercising Tribal Fishing Rights

Tribes within the United States have a unique relationship with the federal government. Tribes are sovereigns and considered domestic dependent nations. Significant case law has developed during the past century and a half. Much of this case law was possible because the tribes are recognized in Article 1, Section 8, Clause 3 of the U.S. Constitution in 1789:

> [T]o regulate Commerce with foreign Nations, and among the several States, and with the Indian Tribes.

Through a review of the negotiation notes that lead to their treaties with the United States, it is obvious that the U.S. negotiators recognized the importance of salmon and first foods to the tribes. Article 3 of the U.S. treaty with the Yakama Nation in 1855 states

> the right of taking fish at all usual and accustomed places, in common with the citizens of the Territory, and of erecting temporary buildings for curing them: together with the privilege of hunting, gathering roots and berries. (Similar language for treaties with Umatilla, Nez Perce, and Warm Springs tribes.)

Through the treaties, the tribes reserved these rights to the first foods, including salmon. These treaties remain legal contracts with the United States and they must be honored.

Despite the treaties, the states began infringing on the tribes' treaty fishing rights as the salmon decline continued to worsen. States began attempting to close tribal fisheries in the 1960s, claiming it was being done for resource protection, even though nontribal fishers were still allowed to fish. Frustrated tribal fishers decided to flout state laws aimed at preventing them from fishing, citing the fishing rights specifically reserved in their treaties with the United States. This was a time of great turmoil; at times, the fishers were even forced to arm themselves for protection while fishing. Eventually the impasse led to the tribal treaty fishing right being challenged in federal court, which resulted in two major court rulings. In the United States v. Oregon (1969) ruling, the court affirmed that the treaties entitled the Yakama, Umatilla, Nez Perce, and Umatilla tribes to a fair share of Columbia River fish runs. The ruling also limited the power of the state of Oregon to regulate treaty Indian fisheries. In the United States v. Washington (1974) case, the court ruling defined "fair share" as 50% of the harvestable surplus and reaffirmed tribal management authority. Both of these cases were eventually affirmed by the U.S. Supreme Court.

Formation of the Columbia River Inter-Tribal Fish Commission

Armed with court rulings that reaffirmed their right to fish and manage the fishery resource, the four Columbia River treaty tribes united forces to address the significant decline of salmon returns. Together, they formed the Columbia River Inter-Tribal Fish Commission (CRITFC) in 1977 to coordinate their management activities and restoration efforts. Since then, these tribes have become leaders in accomplishing their stated goal to "put fish back in the rivers and protect the watersheds where fish live." They participate in interstate agreements and international treaties controlling salmon harvest and water management. These tribes are also successfully rebuilding naturally spawning salmon populations, restoring habitat, and protecting the water flowing in the rivers. Initially focusing on salmon and steelhead, CRITFC's efforts have since expanded to include Pacific Lamprey *Entosphenus tridentatus* and White Sturgeon *Acipenser transmontanus*, the two other anadromous fish species found in the Columbia basin.

Northwest Power Act

The hydroelectric dams on the Columbia River have one of the largest impacts on salmon and steelhead (anadromous Rainbow Trout *Oncorhynchus mykiss*) in the basin. Recognizing this, the tribes were part of the coalition that worked to pass the Pacific Northwest Electric Power Planning and Conservation Act in 1980. This act addresses the impact of hydroelectric dams on fish and wildlife. The act established the Northwest Power and Conservation Council (two representatives from Oregon, Washington, Idaho, and Montana) and directed the council to adopt a regional energy conservation and electric power plan and a program to protect, mitigate, and enhance fish and wildlife on the Columbia River and its tributaries. The act also set forth provisions that the Bonneville Power Administration must follow in selling power, acquiring resources, implementing energy conservation measures, and setting rates for the sale and disposition of electric energy.

Among other things, the act is intended to ensure the Pacific Northwest of an adequate, efficient, economical, and reliable power supply; provide for the participation and consultation of the Pacific Northwest states, local governments, consumers, customers, users of the Columbia River system (including federal and state fish and wildlife agencies and Indian tribes), and the public; develop regional plans and programs related to energy conservation and renewable energy sources; facilitate the planning of the region's power system; and provide improved environmental quality. Concurrent with these actions, the act also requires planning and action to protect, mitigate, and enhance the fish and wildlife resources of the Columbia River and its tributaries, particularly for the anadromous fish, including their related spawning grounds and habitat.

Wy-Kan-Ush-Mi Wa-Kish-Wit

Several salmon populations were listed as endangered or threatened under the Endangered Species Act, beginning in the early 1990s. Due to years of frustration at federal inaction to develop required recovery plans to address salmon survival at all life stages, the tribes developed their own plan to rebuild fish populations. The plan is called Wy-Kan-Ush-Mi Wa-Kish-Wit (Spirit of the Salmon). Wy-Kan-Ush-Mi Wa-Kish-Wit is a restoration plan developed through CRITFC by the four member tribes in 1995 (CRITFC 1995; http://plan.critfc.org/vol-1). The plan was updated in 2014 (CRITFC 2014; http://plan.critfc.org).

To date, this is the only plan that addresses the full lifecycle of the anadromous fish species for the entire Columbia River basin. The plan seeks to halt the salmon decline and sets specific numeric goals for full recovery of Columbia basin salmon, steelhead, Pacific lamprey *Entosphenus tridentatus*, and White Sturgeon *Acipenser transmontanus*. It has a goal of doubling the 1995 salmon runs by the year 2020. The plan provides for the full recovery of anadromous fish to the rivers and streams that support the historical, cultural, and economic practices of the tribes within seven human generations. The seven-generation goal is a common theme for tribes that guides decision-making processes to meet the needs of the next seven generations of their people.

In 2012, the tribes declared that the salmon decline had been reversed. Much work remains to achieve the doubling goal, but recent salmon returns have been as high as 2.5 million fish, which is a significant improvement. The goals for lamprey and sturgeon are similar: the tribes want to halt the population declines and restore populations to fishable populations throughout their historical spawning range.

Using Hatcheries to Restore Salmon Populations

The ceded lands of the CRITFC member tribes are in the middle of the Columbia basin, beginning above Bonneville Dam. For this reason, tribal interests are focused on fish populations that are destined to return above that dam. The states and federal agencies established a substantial number of salmon hatcheries prior to 1980 to mitigate for salmon mortalities caused by dams. Unfortunately, the states and federal agencies focused most of that hatchery production in the lower Columbia River below

Bonneville Dam, where large, nontribal recreational and commercial fisheries would benefit. As a result, the hatchery mitigation benefit accrued primarily in the nontribal fishery and not the tribal fishery. Since the 1980s, the tribes have sought hatchery reform practices by moving the release locations above tribal fishery locations to facilitate tribal harvest as the salmon return to their natal spawning areas. Over time, the situation regarding location of hatcheries and release of hatchery fish have improved to better address the losses above Bonneville Dam, but a vast inequity of hatchery mitigation still exists.

There are two types of hatchery programs currently in use in the Columbia basin: conventional harvest augmentation, and supplementation programs. Conventional harvest augmentation programs operate to mitigate for lost production associated with development of the hydropower system. Most hatcheries upstream of Bonneville Dam continue to fulfill this role and support the Zone 6 tribal fishery located between Bonneville and McNary dams.

Supplementation programs are intended to use biologically appropriate fish (e.g., fish whose origin is from the host natal stream) in a hatchery environment to rebuild natural spawning populations. The reason for this approach is that abundance levels of natural populations throughout the interior basin are too depressed to provide significant tribal harvest and in many cases are so low that the long-term sustainability of the populations is threatened. Since the 1980s, the tribes have advocated for hatchery-based supplementation programs to help rebuild natural populations. Unlike conventional harvest augmentation hatchery programs, supplementation hatcheries use adults captured in-river as broodstock, including a portion that are of natural origin. Their progeny is reared in a hatchery but are released into natural spawning areas to imprint. When they migrate to spawn, they will return to these areas instead of the hatchery, thus supplementing the naturally spawning population. In most cases, this does not require new hatchery construction, but reform of existing hatchery programs to provide a hatchery fish product for a different purpose. The tribes now manage or comanage, with federal and state partners, several supplementation hatchery programs in the interior basin.

The increasing role of tribes in hatchery management is controversial in the Columbia basin. Opponents challenged the scientific integrity of the tribal programs, especially as related to the supplementation hatcheries. The tribes met this challenge successfully. According to a study of the Nez Perce Tribe's Johnson Creek Artificial Propagation Enhancement Project (Hess et al. 2012), researchers found that with biologically appropriate fish, hatchery-reared salmon that spawned with wild salmon had the same reproductive success as salmon left to spawn in the wild. The study focused on a population of summer Chinook Salmon *Oncorhynchus tshawytscha* whose natal stream is located in central Idaho, almost 700 mi (1,100 km) upstream of the Pacific Ocean. The results of the Johnson Creek artificial propagation study refute a commonly held misconception and some previous research suggesting that interbreeding of hatchery-reared fish with wild fish will always decrease productivity and fitness of the wild populations. In fact, the Johnson Creek research demonstrates how supplementation programs are able to increase populations and minimize impacts to wild fish populations. The tribal approach to hatchery management is to use these facilities as a tool to rebuild naturally spawning populations: wild salmon nurseries, as described in the supplementation recommendation of the Wy-Kan-Ush-Mi Wa-Kish-Wit 2014 update (CRITFC 2014). The tribes have shown success in many locations in the Columbia River basin for spring and fall Chinook Salmon, and Coho Salmon *O. kisutch*. Most notably, the success of fall Chinook in the Snake River basin has brought the population from the brink of extinction with only 78 wild fish past Lower Granite Dam in 1990 to more than 60,000 fall Chinook in 2014, half of which were natural-origin fish.

The tribes have shown that supplementation hatcheries can be a powerful tool for restoring naturally spawning populations, in particular to tributaries where the usual and accustomed tribal fisheries are protected under the treaties of 1855. The tribes' motivation is to restore fish populations to historical levels, which is a benefit for all fisheries, tribal and nontribal alike.

Water Quality and Tribal Fish Consumption

When the tribes signed the treaties in 1855, they never envisioned that water quality would become so degraded, nor that consumption of contaminated fish would be an issue. At the time of treaty signing, tribal members drank directly from the Columbia River. Today, a host of contaminants in the river makes this unadvisable and even dangerous. The fish, however, do not have a choice when it comes to the water; they must swim in the river. By doing so, the fish are exposed to and absorb these contaminants. The state governments set fish consumption recommendations based on the amount of contaminants found in the fish. In the past, these rates were based on the amount of fish the average citizen consumes and did not account for the higher levels consumed by tribal members. A CRITFC study completed in 1994 concluded that tribal members consume an average of 6–11 times more fish than the general public. The results of a U.S. Environmental Protection Agency fish contaminant survey, completed in cooperation with CRITFC, showed that 92 priority pollutants were detected in resident and anadromous fish tissue collected from 24 different tribal fishing sites on the Columbia River (USEPA 2002). Contaminants measured in these fish included polychlorinated biphenyls, dioxins, furans, arsenic, mercury, and dichlorodiphenyldichloroethylene, a toxic breakdown product of the pesticide dichlorodiphenyltrichloroethane. As a result, the tribes raised a substantial concern that state water quality standards were not sufficiently protective for the tribal community that still subsisted on large numbers of salmon in their diet.

In 2011, Oregon adopted water quality standards based on the tribal fish consumption rate of 175 g/d, the fish consumption levels documented in the CRITFC survey. Currently, water quality standards for Washington and Idaho are 6.5 g/d and tribal fish consumption rates are at the center of debates related to revising these standards. Washington and Idaho are in the process of revising water quality standards and hopefully will better protect tribal consumers. In 2012, the U.S. Environmental Protection Agency disapproved Idaho's request to use an updated fish consumption rate of 17.5 g/d because it was not protective of tribal consumers. If water quality standards for either state do not provide adequate protection for tribal subsistence populations, then the federal government will need to step in and promulgate water quality standards to protect the tribal members.

When the tribes signed the treaties in 1855, contaminated fish were not part of the deal. Large-scale pollution is a result of both federal and nonfederal actions. The damming of the Columbia basin has exacerbated this problem. Despite these concerns, tribal members continue to consume large amounts of fish for subsistence purposes. Salmon are a healthy food source and must be protected for human consumption. In 2013, CRITFC's chairman submitted letters to the region's governors advocating for stricter water quality standards based on the higher tribal fish consumption rates. He stated, "The tribes believe that the long-term solution to this problem isn't keeping people from eating contaminated fish, it's keeping fish from being contaminated in the first place."

Climate Change

Climate change impacts threaten tribal first food resources, culture, ways of life, and treaty rights. Considerable efforts have been made in the Columbia basin to develop strategies to protect and restore populations of salmon, lamprey, and other imperiled coldwater fish, but most of these efforts have generally not addressed climate change. Climate change is expected to significantly alter the ecology and economy of the Pacific Northwest during the 21st century. Rising air temperatures are expected to decrease snowfall and increase rainfall during the winter months, leading to shifts in the timing and quantity of runoff, including increased flooding during the winter when water is already in ample supply and decreased flows during the summer when water demands are high. These changes will have significant impacts for freshwater fisheries, hydropower production, and water supply for agriculture and municipal uses.

The impacts from climate change will affect salmon in a number of ways. Some examples include alteration of salmon migration patterns, degradation of salmon spawning and rearing grounds, and an increase of predators and aquatic contaminants. If not addressed, all of these factors could lead to salmon extinction.

During the past 50 years, tribes have made incredible strides in the federal courts toward protection of environmental and cultural resources. There are more and more opportunities for the tribes to participate and integrate traditional knowledge in regional and international forums addressing climate change issues.

Columbia River Treaty

The Columbia River Treaty between the United States and Canada governs hydropower and flood control on the 1,200-mi (1,900 km) Columbia River. The current treaty, implemented in 1964, does not consider the needs of fish, a healthy river, or the tribes' treaty fishing rights and cultural resources that are now recognized and fully protected under modern laws. The tribes were not consulted during the initial negotiation of the Columbia River Treaty. As a result, the treaty fails to include tribes or tribal interests. The impacts of the Columbia River Treaty on the tribes' cultural and natural resources multiplied the already disastrous effects that had resulted from the decision by the United States to dam the Columbia River in the 1930s.

In 1944, the United States and Canada began investigations with a broad charge for a mutually beneficial and collaborative treaty, examining not only power generation and flood control coordination, but also including ecosystem needs and other joint uses of the river. This broad scope was narrowed after a major flood in 1948 that caused damage in communities along the river from the mouth at Astoria, Oregon all the way to Trail, British Columbia. The flood completely destroyed Vanport, Oregon, the second-largest city in the state. The loss of life and property spurred the two countries to prioritize an international water treaty that focused solely on coordinated hydropower and flood control operations. The ecosystem and other interests were relegated to each nation's domestic processes. The treaty required the construction of Duncan, Arrow, and Mica dams in Canada and allowed the United States to build Libby Dam in Montana, creating more than 20 million acre-feet (24.7×10^9 m^3) of new storage. Under the treaty, the United States paid Canada US$64.4 million to provide 8.95 million acre-feet (11×10^9 m^3) of storage in Canada for flood control in the lower Columbia, but it is only guaranteed through 2024. The United States returns to Canada half of the downstream power benefits the new Canadian storage produces in the United States. The United States purchased the first 30 years of this power, called the "Canadian Entitlement," for $254 million. The United States began returning the Canadian Entitlement to Canada in 1998. This annual return of power is now valued at $250–350 million per year.

The United States and Canada negotiated the Columbia River Treaty to last at least 60 years (2024). After that date, either party may choose to terminate it, but they must provide a 10-year notice of their intent to do so. That 10-year window opened in September 2014. Seeing that date on the horizon, many tribes in the Columbia basin started taking actions in 2007 to secure seats at the table to contribute to analyses and participate in the decision-making process. These efforts have grown into a coalition of 15 Columbia basin tribes that are actively working with several federal agencies and four states to reshape the Columbia River Treaty to protect and benefit tribal culture and resources. The coalition of 15 tribes also coordinates with 17 First Nations in Canada to provide information on fish passage and ecosystem needs to inform all sovereigns and stakeholders in the basin.

The tribes' participation in the Columbia River Treaty 2014–2024 review is critical for protecting tribal rights and interests, including improving ecosystem functions and ensuring favorable conditions for other tribal resources. The tribes also seek representation on the U.S. negotiating team if changes to the Columbia River Treaty are discussed with Canada. The tribes gained the agreement of the United States to regard ecosystem function as co-equal with flood control and power production during the treaty review and to include measures to restore and preserve tribal resources and culture. Tribal interests were included in the *U.S. Entity Regional Recommendation on the Future of the Columbia River Treaty After 2024* (U.S. Entity for the Columbia River Treaty 2013) submitted to the U.S. Department of State in December 2013. The U.S. Department of State retains the authority to renegotiate international treaties but did use the regional recommendation as a key resource during its national interests determination regarding the future of the treaty. The regional recommendation is unique in that it includes the broad consensus of 11 federal agencies, four states, 15 tribes, the power sector, water users, environmental groups, and others. The U.S. Department of State indicated early in the review process that the ability to reach a regional consensus would govern its decision about whether or not to renegotiate the Columbia River Treaty.

Flood Risks and Benefits

Historically, salmon smolts traveled to the ocean during the freshet that occurred as the winter snowpack melted. This natural pattern was dramatically changed by the implementation of the Columbia River Treaty, with its specific goal of reducing the size of this annual event. The dams and careful reservoir control called for in the treaty reduced the annual freshet from an average of about 500,000 ft^3/s (14,160 m^3/s) to an average of about 275,000 ft^3/s (7,790 m^3/s). The operation of the treaty dams shifted much of the river's flow to occur during the fall and winter months for downstream power generation benefits, a time when salmon smolts were not able to take advantage of it. The treaty and the dams it authorized have changed the entire ecosystem and eliminated all the benefits that river flooding provide.

Floods are a natural and beneficial characteristic of river systems. Flooding is viewed negatively because people have moved into the floodplain, thus putting themselves into harm's way. As dams lowered the likelihood of major flooding, more and more people moved into the historical floodplain. This, in turn, increased the demand for even stricter water control to protect floodplain property. However, even with all of the reservoir storage capacity in the Columbia basin, it is still impossible to perfectly control flooding in the floodplain. Additionally, this demand for perfectly predictable and constant river flows is in opposition to the ecosystem's need for flooding. The Columbia basin tribes do not believe this is an either/or situation and are confident that the needs of major flood prevention can be balanced with the seasonal increases in flows required by salmon and for ecosystem functions. A public discussion is needed to discuss how best to modernize our approach to regional flood-risk management. Regardless of whether or not the Columbia River Treaty is renegotiated, a public review of flood-risk management is required because the Columbia River Treaty does not go away in 2024. Without intervention to modernize the treaty, the flood-control provisions become automatically worse in the United States, putting extreme operational demands on U.S. facilities and increasing the burden on the tribes' resources and healthy ecosystem function. With climate change also a significant consideration, the United States has strong motivation to modernize flood-risk management.

A primary objective of the Columbia River Treaty is to keep Portland from being flooded. Ironically, the United States and Canada agreed to accomplish this objective under the treaty by flooding vast sections of the Columbia basin in Canada. Lands that were never underwater are now flooded by reservoirs for a substantial portion of every year, with some becoming mud flats and then dust bowls as the water is drawn down for power generation. These dams and many other dams in the Columbia basin accomplished flood control by creating permanent floods behind these dams, which destroyed towns, economies, indigenous communities, and the ecosystem. It is important to note that progress came at a great cost, and mitigation for these costs has not come close to the sacrifices of the region. Now is the time to begin a discussion about whether these were good decisions and whether these actions can be reversed. The review of the Columbia River Treaty has provided a backdrop for these discussions.

Restoring Fish Passage to Historic Locations

Since the late 1800s, governments and private interests in the United States and Canada have constructed more than 1,000 dams in the more than 160,000 mi^2 (414,400 km^2) of the Columbia basin that were historically accessible to anadromous fish. Many Columbia basin dams completely block fish passage into the watershed's upper reaches. Dams obstruct passage of salmon and other anadromous fish between spawning and rearing habitat and the Pacific Ocean. Where fish passage was not provided, extirpation of the upstream population was the result. Dams and other water resource developments made more than 55%, or nearly 100,000 mi^2 (259,000 km^2), of the historical spawning and rearing habitat inaccessible to salmon, lamprey, and sturgeon.

Extensive work throughout tributary watersheds has restored passage to more than 15,000 mi^2 (38,850 km^2) of this habitat. The remainder, about 80,000 mi^2 (207,200 km^2), is still blocked. The largest blockages occur in the upper Columbia River at Chief Joseph and Grand Coulee dams and in the Snake River at the Hells Canyon Complex. Construction of Grand Coulee Dam eliminated approximately 1,100 mi (1,770 km) of spawning habitat and extirpated the largest number of known anadromous populations relative to other projects.

On the Snake River, the construction of the three-dam Hells Canyon Complex in the 1950s and 1960s blocked nearly 2,000 mi (3,200 km) of anadromous fish habitat. Additional spawning habitat was lost following construction of other main-stem and tributary dams. In total, more than 30% of the habitat originally available to salmon in the Snake River basin has been lost. The extent of fishing by native peoples also measures the magnitude of damage. Above the four lower Snake River dams, for example, tribal fishers are presently harvesting salmon at less than 1% of precontact levels while Pacific Lamprey are not harvested due to extremely low adult returns.

Downstream of the Chief Joseph, Grand Coulee, and Hells Canyon Complex dams, other dams block salmon and lamprey habitat in virtually all the tributaries. Small hydroelectric dams and irrigation diversion dams dot the landscape, excluding or impeding passage to spawning and rearing habitat above. Forestry practices and poorly designed roads and culverts create additional blockages to an undeterminable number of tributary streams and habitat miles.

Initiated in large part by the Columbia River Treaty review process, the Columbia basin tribes and First Nations cohosted both a technical workshop and a major conference on restoring fish passage in 2014. Based upon the information shared during the technical workshop and the Future of Our Salmon Conference, it is clear that fish passage can be restored above the Chief Joseph and Grand Coulee dams and into the spawning grounds in Canada. With these findings, the Columbia basin tribes and First Nations released a joint report on restoring historical fish passage in January 2015.

Many tribes and First Nations have been without salmon for decades—a major blow to their cultures and relationship with the Creator. Now is the time to right this wrong and restore fish passage to historical locations.

Tribal Communities Displaced by Dam Construction

The U.S. Army Corps of Engineers (USACE) built four dams on the main-stem Columbia River that inundated the four treaty tribes' usual and accustomed fishing places and fishing villages along that stretch of river. This inundation also impacted nontribal communities located along the river. To mitigate for the impact on tribal communities, Congress designated federal lands as mitigation in the River and Harbor Act of 1945 (Public Law 79-14) and, in 1988, directed the USACE to acquire private lands and construct the needed infrastructure for this purpose in Title IV of the Southern California Indian Land Transfer Act (Public Law 100-581).

Most of the nontribal communities affected by the inundation have received compensation or relocation assistance. Indeed, many nontribal communities were relocated with federal funding and support almost immediately after the dams were constructed. The most recent nontribal community to be relocated was North Bonneville, which was relocated in 1978 due to the construction of the second powerhouse at Bonneville Dam.

Most of the tribal community along the Columbia River, however, is still waiting for relocation assistance since the USACE constructed Bonneville Dam in 1938, The Dalles Dam in 1957, and John Day Dam in 1971. Between 1996 and 2011, the USACE purchased private land for tribal use to provide tribal fishers access to their usual and accustomed fishing areas. The USACE constructed infrastructure at these sites for camping, fishing access, and ancillary fishing facilities. The federal government still has an outstanding and ongoing obligation to analyze and undertake remediation and mitigation projects for loss of tribal homes and access to usual and accustomed lands. This obligation includes infrastructure development for the cultural, social, environmental, religious, and traditional practices lost to the tribes because of federal hydroelectric development of the river. Federal development of the Columbia River hydropower system has resulted in persistent poverty and unhealthy and unsafe living conditions for tribal members living along the river. Currently, the most urgent need is for housing and supporting infrastructure. The unfair treatment of the tribal community has garnered the attention of numerous news outlets in recent years. The U.S. Congress needs to authorize and appropriate adequate resources to the USACE to complete the relocation assistance. This has yet to occur.

River Damming on a Global Scale

On a global scale, clearly there is no relief beyond Earth. The large-scale damming of rivers around the planet has and will continue to cause great harm to the earth's ecosystem. This, in turn, will damage food sources in the ocean and in our rivers, damage local economies, and cause substantial impacts to indigenous communities that may not enjoy the same legal protections that nonindigenous communities enjoy. There is still much to learn about the global relationship of inland waters and the ocean. What is known, however, is that there will be considerable damage from major dam building that will have irreversible effects.

Conclusions

The U.S. Constitution protects tribal rights. The tribes' treaties with the United States have not only protected the tribal fishing rights, they have provided crucial legal leverage that is helping drive current salmon recovery efforts. As such, tribal litigation was a powerful tool to address the needs of salmon and tribal fisheries. Litigation will continue to be a powerful tool. However, public and private partnerships are often stronger than litigation when used to achieve successful salmon rebuilding programs and meet other public policy objectives.

Despite many daunting challenges, the tribes never strayed from their mission to protect salmon. Remarkably, the salmon decline has been reversed. The tribal work has only begun, but the success of tribal efforts will benefit future generations, tribal and nontribal alike.

Tribal ecological knowledge has guided the development of the member tribes' and CRITFC's science programs. A key element of this traditional wisdom is the view that people are a part of the ecosystem (e.g., deep tribal connection to first foods). Changes to the ecosystem also affect humans. People are not outside of the ecosystem, nor does the ecosystem exist solely for human use. Humans would all be better off if they viewed themselves as a part of the ecosystem. If more people realized this, there would be much better decisions where the environment is concerned.

Ecosystem-based governance is key to our success as Earth's inhabitants, including contributions by indigenous communities to the decision-making process. We owe this to our future generations.

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Freshwater Fish in the Food Basket in Developing Countries: A Key to Alleviate Undernutrition

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The Challenge: The One-Thousand-Day Window of Opportunity to Improve Nutrition

How can freshwater fish contribute to improved diets and nutrition in food insecure populations with people who are either undernourished or at risk of becoming undernourished? With a focus on the nutritional problems typically affecting food-insecure populations, there may be ways to increase the contribution from freshwater fish resources to alleviate these nutritional problems for better health. Linking primary food production—mainly focusing on agriculture but equally relevant for fisheries—to the nutritional problems in food insecure populations is being investigated within the framework of nutrition-sensitive agriculture (Jaenicke and Virchow 2013). Food systems are being investigated for possible ways to be reshaped in order to narrow the gap between the food supplied and the required nutrients needed for a more balanced diet in vulnerable populations (Pandya-Lorch and Fan 2014).

What are the global nutritional problems of concern? Good nutrition is needed for all throughout life, but the consequences of poor nutrition is particularly critical in early life during the 1,000-d period from conception through pregnancy and the first 2 years of a child's life (Bogard et al. 2015). Infants and young children are also particularly vulnerable to not being able to fulfil their nutritional requirements due to the relatively high physiological demands for energy and nutrients for rapid growth and development and limited stomach capacity.

Growth in infants and young children is assessed by comparing the individual's growth with growth standard curves for healthy children. Poor nutrition in early life can either occur as acute energy deficiency leading to low weight (wasting) and/or chronic deficiency of nutrients and energy over a long time leading to chronic undernutrition manifested as stunting (shortness). While wasting is immediately life-threatening, shortness may not appear critical. However, stunting is documented to be associated with many health implications, including impaired physical and cognitive development (Victora et al. 2008) and increased risk of mortality (Black et al. 2013). Out of the more than 6 million children who die annually before the age of 5 years, the death of 3 million (44%) children are related to undernutrition, and of these, 1 million children die from complications that are linked to the fact that they were stunted as a result of poor nutrition and living conditions throughout their short lives (Black et al. 2013).

Although there is some encouraging progress in reducing global undernutrition, including stunting, the number of stunted children was 165 million in 2011 (Black et al. 2013), an unacceptable level. The present rate of reduction is far too slow to eliminate stunting as a public health problem within a reasonable time. With the present progress in improving nutrition, the number of stunted children in 2025 is predicted to remain high, estimated to 127 million (IFPRI 2014). Targeted efforts to improving access to nutritious foods and diets during the 1,000-d period are crucial to reduce undernutrition in food-insecure populations.

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The Role of Fish in the Food Basket

Fish is a nutritious food source that adds high-quality protein, fat with beneficial fatty acids, bioavailable vitamins, and minerals, as well as diversity and palatability, to the diet. Deficiencies of specific nutrients such as vitamin A, iron, zinc, and iodine are well-documented public health problems in food-insecure populations (Black et al. 2013; IFPRI 2014), and the importance of a diverse diet with contributions of animal-source foods (fish, meat, milk, and eggs) for prevention of undernutrition is also evident (Arimond and Ruel 2004; Allen 2012). Fish in the diet can contribute to diversity and most of the nutrients commonly scarce or deficient in diets.

What role does freshwater fish play in populations now affected by undernutrition, and how can freshwater fisheries resources contribute to speeding up global progress in alleviating undernutrition? The role of fish and seafood, including freshwater fish, was reviewed for any indications of whether countries with high availability of fish were less affected by stunting in children. Seafood supply data at the national level were extracted from Food and Agriculture Organization of the United Nations (FAO) statistical databases (FAO 2014) for selected countries with a range of high to low supplies of fish (3–65 g fish/person/d), and also having a gradient of prevalence of child stunting (10–41% of children <5 years of age stunted; Table 1; FAO 2014; WHO 2015). There are no indications that a higher average per capita fish supply at the national level prevents stunting in children. This does not support a conclusion that fish is not important for nutrition in these countries, but indicates that securing a high fish supply at the national level does not necessarily lead to better nutrition. The relative contribution of fish to diets is not reflected in the fish supply data. The importance of fish relative to other foods varies between countries. For example, in Bangladesh, more than half of the dietary animal protein available for the population comes from freshwater fish. This share of protein supplied from freshwater fish is higher than in any other country. The nutritional situation in Bangladesh is poor and more than 40% of children are stunted, caused by other dietary factors than fish intake as well as non-dietary factors such as poor water, sanitation, and hygiene.

National supply data for average per capita availability of freshwater fish covers large variations in consumption of fish between socioeconomic, ethnic, and age population groups. Dietary surveys in food-insecure populations with access to freshwater fish resources show that fish is often consumed daily or several times per week, even in poor

Table 1.—Supply of total seafood, including marine and freshwater fish and other aquatic animals (FAO 2014) and the prevalence of stunting among children less than 5 years of age (WHO 2015) in selected countries.

Country	National total seafood supply (freshwater fish supply)[a] g/person/d	Stunting prevalance among children under 5 years of age (%)
Ghana	65 (7)	28
Indonesia	49 (11)	36
Vietnam	44 (17)	23
China	38 (23)	10
Bangladesh	26 (23)	41
Mexico	21 (2)	16
South Africa	14 (0,2)	24
India	9 (6)	48
Bolivia	3 (1)	27

[a] National total seafood supply including marine and freshwater fish and other aquatic animals.

households (Roos et al. 2003). However, even though fish is consumed very frequently, the portion sizes can be too small to have nutritional significance. For example, in Cambodia, children's diets contained portion sizes of fish as low as 3 g, just a teaspoon (Skau et al. 2014). If a meal contains only few grams of fish—for example, dried fish added to a mixed dish to add flavor—or a few small-sized fish are shared among many family members, the nutritional contribution is not sufficient to have an impact on health.

Inland Fisheries Can Contribute to Improve Dietary Quality and Improve Nutrition

Freshwater fish is a highly nutritious food source and has the potential to contribute much more to reducing the problems of chronic undernutrition and stunting. What actions can release this potential and transfer into improved nutrition?

The International Food Policy Research Institute (IFPRI) analyzed scenarios for the impact of investing in health and nutrition interventions for reduction of stunting to either 15% or less than 10% among children less than 5 years of age in 116 developing countries by 2015 (IFPRI 2014). The analyzes showed that along with basic health interventions such as improving access to safe water and sanitation, a key to reducing stunting is to improve the quality of the diet through a higher intake of nonstaple foods (Table 2). As stunting in children is the result of poor livelihoods, including poor diets, access to clean water and basic sanitation, as well as girls' schooling, are needed to reduce the risk of stunting. The IFPRI scenario analyzes showed that to achieve a reduction of stunting to less than 10% in 2025, 98% of all households need to have access to clean water and schooling for girls, and access to improved sanitation, mainly toilets, also needs to be drastically improved and be available in 9 out of 10 households. Diets also need to be improved to achieve a significant reduction in child stunting. Total food intake (dietary energy) needs to increase by around 10%, from an average of 2,686 kcal/person/d to around 2,900 kcal/person/d. However, this increase in average dietary energy intake should mainly be contributed by nutritious nonstaple foods, not from more carbohydrate from rice, wheat, or maize. A contribution of 54% of energy from nutritious nonstaple foods is necessary in order to reach the more ambitious scenario of reducing stunting to less than 10%. Having more fish in the diet is an important contribution to nutritious nonstaple foods and improved dietary quality.

Targeted actions through programs and policies should support freshwater fish resources playing a larger role in improving diets of women and young children and thereby reducing stunting, which can have a positive impact on reducing child mortality.

Nutritional Quality of Fish

Fish provides high-quality protein and important fatty acids, vitamins, and minerals. Fatty acid composition is of specific interest

Table 2.—Some determinants identified for successful reduction in stunting in 116 developing countries by 2025 (IFPRI 2014).

Determinants	2010 situation: stunting rate 29.2%	Reduce stunting rate to 15% by 2025	Reduce stunting rate to <10% by 2025
Access to improved water source (%)	86	98	98
Access to improved sanitation facility (%)	56	75	90
Female secondary school enrollment (%)	67	98	98
Dietary energy supply per capita (kcals/d)	2,686	2,905	2,930
Share of dietary energy supply from nonstaple food (%)	43	48	54

as aquatic organisms are good sources of essential n-3 and n-6 fatty acids and also provide the valuable long-chain polyunsaturated fatty acids (LCPUFA) docosahexaenoic acid (22:6n-3), and eicosapentaenoic acid (20:5n-3). Growth retardation is one of many physiological consequences of deficient intakes of n-3 and n-6 fatty acids and one factor in the complexity of stunting. Long-chain polyunsaturated fatty acids are specifically important for brain development and thereby cognitive performance (Lauritzen et al. 2001). All fish contain essential fatty acids, but not all fish species are equally good sources of n-3 fatty acids and LCPUFAs. Coldwater fish species tend to have a higher content of LCPUFAs compared to the warmwater fish (Michaelsen et al. 2011).

The recommended intake of the essential n-3 fatty acid (linolenic acid, 18:3 n-3) in young children is 0.4–0.6% of the dietary energy (%*E*), and 4–6%*E* for essential n-6 fatty acid (linoleic acid, 18:2 n-6) (Michaelsen et al. 2011). There are little data available on actual intakes of essential fatty acids in populations. In Figure 1, the %E supplies of n-3 (A) and n-6 (B) from foods in 10 selected countries are shown as function of the economic status of the countries expressed as gross domestic product. The countries represent a wealth gradient from low- to middle-income countries. Data are extracted from FAO's statistical database (FAO 2014). The ranges for the recommended intakes of n-3 and n-6 fatty acids in children are marked in Figure 1 to indicate whether the countries may be at risk of having deficient supplies of n-3 and n-6 fatty acids. People in the poorest countries are particularly at risk of being deficient in essential fatty acids. Bangladesh has the lowest n-6 supply among the selected countries due to a very low total fat supply. However, the n-3 supply in Bangladesh is less critical and above other poor countries because of the relatively good supply of fish. While n-6 fatty acids are often supplied by plant sources, animal-source foods, particularly fish, are important—but not the only—contributors of n-3 fatty acid. The food supply data originating from the FAO statistical database is associated with uncertainties, but do provide an important indication that the supply of essential n-3 fatty acids are likely to be critically low in many populations. Children and women are particularly vulnerable and, therefore, benefit most from consumption of fish, including from freshwater sources (Michaelsen et al. 2011).

In addition to protein and fat, fish also supplies vitamins and minerals. There is considerable variation in the contents of different

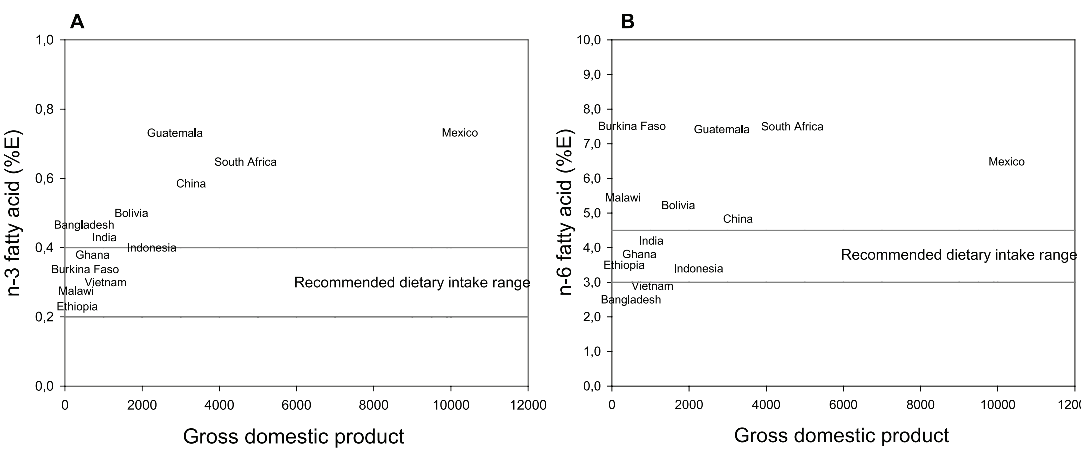

Figure 1.—Supply of **(A)** n-3 and **(B)** n-6 fatty acids from the national food supply in selected countries with variable economic situation (gross domestic product). The range for recommended dietary intake for infants and young children expressed as percent of dietary energy intake (%*E*) is shown.

vitamins and minerals among species, and an important factor is which parts of the fish are actually eaten. Cultural perceptions and individual preferences are determinants for which parts of a fish, for example the head, are considered edible. Studies in Bangladesh and Cambodia showed a large variation in vitamin A content among small indigenous fish species (Roos et al. 2002, 2007a), with a single species, Mola *Amblypharyngodon mola* having levels 100 times higher than other species from the same freshwater environment. Almost all the vitamin A in Mola is located in the eyes or the viscera —specifically the liver—of the fish. Therefore, an important determinant for the dietary value of Mola is whether the head, as well as the viscera, are considered to be edible (Roos et al. 2002). Compared to large fish species, for example carp produced in aquaculture and for which only the fillets were eaten, the small indigenous fish species, which were eaten whole, were a very important source of vitamin A.

Small fish were also an important source of calcium because unlike the larger fish, the bones of most of the small fish species were eaten. Based on a household study in Bangladesh and the analyzed contents of calcium in whole, raw fish, Roos et al. (2003) developed a correction factor to estimate the content of calcium in the edible parts of different fish species based on whether the bones were consumed or not. For large fish, the bones were reported never to be eaten and, therefore, the dietary contribution from these fish species would be insignificant. The small fish with soft thin bones such as Mola and Chanda *Parambassis baculis*, on the other hand, were an excellent source of calcium because more than 90% of the bones were eaten. For other species, the contribution to calcium intake was reduced, though still valuable, because the bones were only partially consumed. Small fish species in general have higher contents of iron and zinc than large fish species (Roos et al. 2007b). In Bangladesh, small fish species are among the most important sources of essential vitamins and minerals in many poor households, although the quantity of consumption is too low to avoid deficiencies.

How Can the Consumption of Fish by Women and Children Increase?

Availability and accessibility of fish to poor households are important to secure higher intakes. However, access alone is not enough to secure intake in women and young children, especially during the critical 1,000 d. There are economic and other barriers to fish consumption, even when available from capture or local markets, for example, cultural beliefs about when to introduce fish in children's diet and a mother's fear of bones getting stuck in the throat of the child (Skau et al. 2014). A general constraint to feeding of infants and young children is that caregivers lack time to prepare nutritious complementary foods during the critical transition from breastfeeding to semisolid foods at 6 months of age, when special baby foods are needed (FAO 2015).

One approach to change dietary habits and promote higher consumption of fish is through nutrition education, for example, training, information campaigns, and cooking demonstrations. Dissemination of dietary guidelines to the population or specific populations groups is used, for example, in most western countries. Dietary guidelines include recommendations about frequency (eat fish twice a week) and/or quantity (eat 200 g fish per week) of fish consumption. Some countries also have recommendations for limiting the intake of fatty, predatory fish species such as tuna during pregnancy because of the risk of exposure to environmental toxins. Nutritional campaigns have variable impact on actual behavior and have the largest impact in privileged populations groups, whereas households with fewer resources are harder to reach, due to lack of schooling, poor health, and often stressful living conditions, which makes adoption of dietary advice difficult. Nutrition education programs in combination with other interventions, such as extension of agricultural practices, have been investigated and evaluated for impact on nutritional status in developing countries (Berti et al. 2004; Kerr et al. 2011). Overall, nutrition education can change dietary habits in some populations, but the chances for success are highest when combined with food production interventions that can make the recommended nutritious food more available, and thereby the adoption of dietary recommendations easier.

In view of the modest success of substantially reducing undernutrition with present efforts, the need for more targeted interventions to increase intake of nutritious foods has emerged. Stunting can begin early. Therefore, it is critical to provide sufficient nutrition to women and children during the 1,000 d. Consequently, increased focus is on the potential of providing nutritious food supplements to be distributed in targeted programs or through, for example, social marketing to reach women and children when they are most at risk of being undernourished (de Pee and Bloem 2009). Food aid products developed for children usually contain milk powder to improve nutritional quality. However, fish can nutritionally substitute milk, and research has been initiated to develop processed food aid products based on fish instead of milk. Such products can be produced locally in the countries or regions where fish are abundant (Kuong et al. 2013; Skau et al. 2015).

Food aid products for food distribution in food insecure populations are widely used by the World Food Programme (WFP), the United Nations Children's Emergency Fund (UNICEF), and many other organizations. There are basically two types of foods, fortified blended foods (FBF) and lipid-based pastes, also known as ready-to-use-therapeutic foods (RUTF) (de Pee and Bloem 2009). Multiple studies over the past 20 years have shown that RUTFs are very efficient in treating severe malnutrition (Briend et al. 2015) while FBF products can be used to prevent vulnerable children from becoming severely malnourished. A key goal is to develop the best products at the lowest price, preferably with local food ingredients to meet cultural preferences, as well as to create jobs and benefit local economies (Bogard et al. 2015). At present, most products used by WFP, UNICEF, and national governments are produced and distributed by few global manufactures.

In the search for the optimal composition of FBF and RUTF food supplements for infants and young children, adding a proportion of milk powder to plant-based products has a positive impact on child growth (Michaelsen et al. 2009). However, milk is expensive and as the use of supplementary food products is projected to expand, reliance on a single food item with a high and fluctuating price is a severe limitation. Therefore, the possibility for using fish as a nutritionally suitable alternative to milk in such products, while, at the same time, being acceptable for consumption, is now being investigated.

In Cambodia, the nutritional impact of using small, indigenous fish in a rice-based, processed porridge (instant baby food) was investigated in the WinFood project (Skau et al. 2015). Two local, fish-based products were developed compared to two standard products used by WFP in food aid programs, of which one WFP product contained milk powder. One WinFood product was made with two fish species (Mekong Flying Barb *Esomus longimanus* and *Paralaubuca typus*; total 12% of dry weight) specifically selected for high contents of micronutrients. In addition, a small amount (2% of dry weight) of an edible spider commonly consumed in Cambodia and found to have high zinc content was added to this WinFood product. The other WinFood product was made with mixed small fish species selected for high local availability and low price. This product was added to a mix of micronutrient fortificant similar to the micronutrients added to WFP standard products.

The foods were tested in a randomized trial in infants who were fed the foods every day for 9 months. The WFP product with milk powder and the WinFood product containing small powdered fish and extra micronutrients were able to prevent the onset of stunting during the first 6 months of the study. The study showed that length growth in children was supported equally well by the fish and milk powder products (Skau et al. 2014, 2015). The food supplements were not able to completely prevent children from being undernourished; however, the nutritional status of these children was better than the overall national level. The food products only provided a proportion of the diet to the children who were also getting breastmilk and other foods. The complete diet was analyzed using linear programming to evaluate whether it could meet the nutrition requirements of the children (Skau et al. 2014). The linear programming modelling indicated that even a daily nutritious food supplement like the WinFood products was not sufficient to fully compensate for the general poor diet, but in combination with general nutrition education, the provision of processed foods with fish and additional micronutrients can make a significant contribution to improve poor nutrition in infants and young children. Small powdered fish were found to be an affordable alternative to milk powder, which is promising for the future use of small freshwater fish in the production of local food supplements. This is highly relevant in Cambodia where milk is expensive and consumption is low while freshwater fish is seasonally available and an appreciated food, but the quantity of fish consumed in the daily diet is too low to prevent undernutrition.

Based on the WinFood results and the collaboration established between nutrition research at the University of Copenhagen, the fisheries research team in Cambodia at The Department of Fisheries Post-Harvest Technologies and Quality Control, and the Institute de Recherché pour le Développment, Montpellier, France, a new lipid-based product with small fish is now being developed for testing in treatment of severely undernourished children (Sigh 2016).

Also, in Bangladesh, the production of processed products with small fish for improved nutrition during the 1,000 d has being investigated (Bogard et al. 2015). WorldFish in Dhaka has developed a processed fish product for children with 15% small fish (dry weight) and a fish chutney supplement for pregnant and lactating women with 37% small fish (final product). These products are well accepted and can be produced locally, making small freshwater fish, often traded at a low price in peak season, into a high-quality product that can support a consistent higher intake of fish during the 1,000 d. The aim of making these products available is to increase the amount of fish consumed in the target groups of pregnant and lactating women and young children, in a population with a habit of frequent consumption of fish but in far too small quantity to significantly impact health and reduce risk of stunting.

Freshwater Fish in the Food Basket in the Future

The examples of processing small freshwater fish into quality products presented here are only one approach to enhancing fish consumption. There are other opportunities to be explored so that more of the fish available from freshwater resources can be channeled into the diets of the nutritionally most vulnerable, thereby improving diets and reducing stunting. The approaches to improving the contribution from freshwater fish to better nutrition should be explored jointly by the inland fisheries sector and the nutrition sector. The opportunities to be considered include

- Utilization: Most inland fish (>90%) landed already goes to human consumption (Welcomme et al. 2010), and unlike marine catches, there is little room for increasing the amount for human consumption. However, on a local basis, there can be ways to ensure better utilization, for example, reducing postharvest losses, especially of small fish.
- Availability: Improved management of inland fisheries may improve availability of freshwater fish for food-insecure populations. Small fish are nutritionally advantageous compared to large fish, and management targeting availability of small-sized fish can improve the nutritional contribution from freshwater fish in the food basket.
- Consumption: Consumption of fish can be low even when fish supply is available. Nutrition education could be integrated into fisheries programs, targeting food-insecure populations to raise awareness of the importance of fish for women in the reproductive age and children.
- Linking nutrition and fisheries in the value chain from catch to consumption: Collaboration between inland fisheries and nutrition sectors can be strengthened to

ensure fish availability and consumption for all, but in particular during the 1,000-d window of opportunity to prevent chronic undernutrition. Through partnerships between the fisheries and nutrition sectors throughout the value chain, freshwater fish can be made available for increased consumption, fresh or in processed products, with the aim of increasing the amount of fish consumed. Thus, the benefit of the highly nutritional qualities of fish can be enhanced and contribute to alleviating undernutrition.

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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 countries (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 (McCafferty 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-

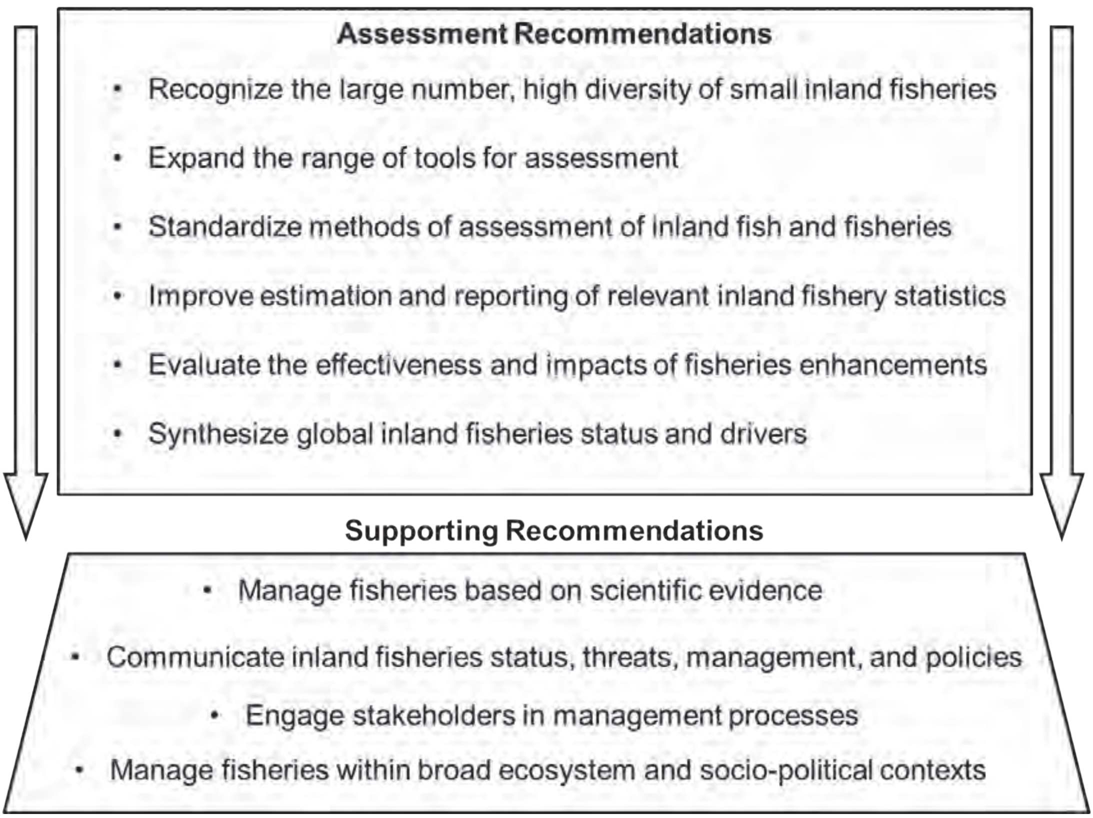

Figure 1.—The 10 priority recommendations derived by attendees of the fisheries assessment symposium as part of the Global Conference on Inland Fisheries held at the Food and Agriculture Organization of the United Nations in Rome in January of 2015. The recommendations are separated into two overarching 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; IFReDI 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 (Muller 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 noninvasive, 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 -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 1.7×10^9 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 overharvest, 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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A Global Estimate of Theoretical Annual Inland Capture Fisheries Harvest

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Abstract.—To better reflect the true value of inland capture fisheries in the international discourse, we provide a new estimate of theoretical annual fisheries harvest from inland waters per continent and type of aquatic habitat. The estimate is based on an assessment of recent estimates of global inland aquatic habitat areas and average yield measurements from these habitats.

We estimate the global theoretical annual inland fisheries harvest to be approximately 72 million metric tons. Our estimates of harvest by continent are on average 6.5 times higher than the official catch data submitted to the Food and Agriculture Organization of the United Nations. Reasons for the higher values in this study are discussed and include the use of improved estimates of global freshwater surface area and yield estimates from a wide variety of water bodies. Improved estimates of the theoretical harvest from inland water capture fisheries would greatly increase the visibility and the importance of the sector and help ensure its proper consideration in policies addressing livelihoods and food security.

Introduction

Freshwater capture fisheries (harvest from wild stocks in inland waters) provide income and nutrition for hundreds of millions of people worldwide (FAO 2014c) and are dependent on functioning freshwater ecosystems. The major external threats to freshwater fisheries are degradation and loss of freshwater ecosystems (Welcomme 2011a) as well as loss of access to those ecosystems. Destructive and unsustainable fishing practices further threaten inland fisheries (Allen et al. 2005), and in many cases, individual species are overexploited. Inland capture fisheries are especially important in landlocked countries in the developing world where they provide an important source of animal protein (Lucas and Marmulla 2000). Countries with significant coastlines (e.g., Kenya, Tanzania, Bangladesh, Cambodia, and Nigeria) are also highly dependent on large inland systems for their fish supply (UNEP 2010).

Africa and Asia together accounted for more than 91.6% (23.3 and 68.4%, respectively) of the reported inland fish harvest worldwide in 2012 (FAO 2014a). Since reporting started in 1950, there has been a steady increase in reported inland capture fisheries harvest, with the current level of annual harvest being approximately 11.6 million metric tons (FAO 2014a, 2014c).

The official reported inland water surface area in the world totals 4.6 million km^2 (FAO 2014b). Globally, this water surface area would correspond to a yield of 25 kg/ha/year or 1.7 kg/person. However, both the inland water surface area estimates of 4.6 million km^2 and the 2012 reported inland capture harvest of 11.6 million metric tons have some concerns attached to them. For the reported inland water areas, this estimate is based on water areas reported by only 67% of the world countries,

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indicating that this estimate must underrepresent the actual inland water area (FAO 2014b). Furthermore, the value of inland capture fisheries is not sufficiently recognized and frequently underestimated, especially in terms of subsistence fisheries in developing countries (Mills et al. 2011). Moreover, recreational fisheries are seldom included in official catch data (Cooke and Cowx 2004). Hence, both officially reported inland water areas and inland capture fisheries harvest figures are likely to be underreported.

Globally, freshwater is a very strategic resource because of its multiple and important uses (e.g., drinking water, hydroelectric generation, and irrigation). This results in high pressure from different freshwater sectors and users, which will most likely increase with a growing population that is estimated to reach 9.6×10^9 in 2050 (UN 2013). The increasing pressure on water resources will put more stress on the inland capture fisheries sector. It, therefore, becomes increasingly important to provide a better estimate of potential harvest from inland capture fisheries and to achieve a better understanding of its importance for food supply and food security. Improving this estimate will also benefit policymakers who rely on this information to make informed decisions about water management.

To better reflect the value of inland capture fisheries, we have extended the idea of Welcomme (2011b), who estimated harvest based on the relationship between lake size and harvest. To this end, we provide further estimates on the theoretical annual harvest from inland capture fisheries per continent and type of aquatic habitat, based on recent estimates of global inland aquatic habitat areas (Lehner and Döll 2004; Downing 2009) and habitat- and continent-specific fisheries yield data. The intention of this exercise is not to provide the exact potential global harvest for inland capture fisheries, but rather to estimate the potential levels of global and regional yields to serve as a basis for further more detailed studies.

Method

A global assessment of area of five different aquatic habitats (AqH) was constructed that included permanent lakes, reservoirs, rivers (including streams), floodplains (including freshwater marches), and other wetlands (including rice fields). The area value ($\text{Area}_{\text{AqH global}}$) for the habitats was determined as the average values from the assessments of Downing (2009) and Lehner and Döll (2004). Swamp forest, flooded forest, bogs, fens, mires, intermittent wetlands, and lakes were grouped together as other wetlands. The following nonfreshwater aquatic habitats were excluded from the analysis as harvest from these systems would not be reported as derived from inland capture fisheries: coastal wetland, pans, and brackish/saline wetlands (De Graaf et al. 2015). The distribution of aquatic habitats per continent ($\text{Area}_{\text{AqH continent}}$) was calculated using the distribution assessment from Tables 4 and 5 of Lehner and Döll (2004).

To obtain a measure of the mean annual fish yield (kg/ha/year) per continent and per aquatic habitat type ($\text{Yield}_{\text{AqH continent}}$), data were collected from (1) the literature, and (2) a Food and Agriculture Organization of the United Nations database (FAO 1997). The latest data were used where there were duplicate measures from the same water body. The compiled data set of fish yield from 793 specific water body areas organized by continent and the five aquatic habitat types was further processed in Statistica 12 (StatSoft, Tulsa, Oklahoma) where outliers where removed until a two-tailed normal distribution was obtained. Thereafter, the mean annual yield and the 95% confidence interval per continent and aquatic habitat were calculated for the remaining data (i.e., 697 specific water bodies).

For 11 aquatic habitats in continents where yield data were missing, the yield was estimated using two different approaches. The following seven aquatic habitats were estimated from the most similar habitat and continent in terms of latitude and average temperature.

1. $\text{Yield}_{\text{River N America}} = \text{Yield}_{\text{River Europe}}$
2. $\text{Yield}_{\text{Other wetlands S America}} = \text{Average (Yield}_{\text{Other wetlands Asia}}, \text{Yield}_{\text{Other wetlands Africa}})$
3. $\text{Yield}_{\text{River Africa}} = \text{Average (Yield}_{\text{River Asia}}, \text{Yield}_{\text{River S America}})$
4. $\text{Yield}_{\text{Reservoirs Oceania}} = \text{Average (Yield}_{\text{Reservoirs Asia}}, \text{Yield}_{\text{Reservoirs Africa}}, \text{Yield}_{\text{Reservoirs S America}})$

5. $Yield_{River\ Oceania}$ = Average ($Yield_{River\ Asia}$, $Yield_{River\ Africa}$, $Yield_{River\ S\ America}$)
6. $Yield_{Floodplain\ Oceania}$ = Average ($Yield_{Floodplain\ Asia}$, $Yield_{Floodplain\ Africa}$, $Yield_{Floodplain\ S\ America}$)
7. $Yield_{Other\ wetlands\ Oceania}$ = Average ($Yield_{Other\ wetlands\ Asia}$, $Yield_{Other\ wetlands\ Africa}$)

Four aquatic habitats where there were no similar habitat data (i.e., temperate data) were estimated by applying a 0.1 factor to the habitat corresponding to the average data for tropical systems as follows:

1. $Yield_{Floodplain\ N\ America}$ = 0.1 × Average ($Yield_{Floodplain\ Asia}$, $Yield_{Floodplain\ Africa}$, $Yield_{Floodplain\ S\ America}$)
2. $Yield_{Other\ wetlands\ N\ America}$ = 0.1 × Average ($Yield_{Other\ wetlands\ Asia}$, $Yield_{Other\ wetlands\ Africa}$)
3. $Yield_{Floodplain\ Europe}$ = 0.1 × Average ($Yield_{Floodplain\ Asia}$, $Yield_{Floodplain\ Africa}$, $Yield_{Floodplain\ S\ America}$)
4. $Yield_{Other\ wetlands\ Europe}$ = 0.1 × Average ($Yield_{Other\ wetlands\ Asia}$, $Yield_{Other\ wetlands\ Africa}$)

The total annual harvest (TFH) from the areas assessed was obtained by multiplying the obtained yields ($Yield_{AqH\ continent}$; mean and 95% mean confidence level) by the aquatic habitat type area ($Area_{AqH\ continent}$).

$$TFH = Yield_{AqH\ continent} \times Area_{AqH\ continent}$$

As a comparison to TFH, we calculated (1) global fish biomass (FB_{Global}), (2) fish production (FP_{Global}) in lakes, reservoirs and rivers, and (3) the theoretical global fish yield from lakes based on net primary production (TFY_{NPP}). The global fish biomass (FB_{Global}) and global fish production (FP_{Global}) for lakes, reservoirs and rivers was derived from the global mean fish biomass (mean FB_{Global}) and mean fish production (mean FP_{Global}) for lakes, reservoirs, and rivers from values in the literature and multiplied by the corresponding global area ($Area_{AqH\ global}$, Table 1).

The theoretical global fish harvest from lakes based on net primary production ($TFHL_{NPP}$) was calculated from the average global value for lakes of 266 g C/m^2/year (Lewis 2011) net primary production (NPP) and converted to fish harvest (Downing et al. 1990) and multiplied with the global area of lakes ($Area_{Lakes\ global}$):

$$TFHL_{NPP} = Area_{Lakes\ global} \times 0.1 \times \log_{10}\left(0.600 + 0.575 \log_{10} NPP\right)$$

Results

The total global area for the five different aquatic habitats that could sustain inland capture fisheries was assessed to be 10,404,450 km^2 (Table 1). Globally, we determined that the water surface area is composed of 30.7% lakes, 2.8% reservoirs, 4.2% rivers and streams, 30.9% floodplains and freshwater marsh, and 31.4% other types of wetlands. The distribution of different aquatic habitats per continent is presented in Table 1.

The mean fisheries yield per continent and aquatic habitat type indicate that the highest mean yields from lakes, rivers and streams, and other wetlands are found in Asia (Table 2). The highest mean yield for reservoirs and floodplains are found in South America, with the lowest mean yields found in North America and Europe.

Table 1.—Distribution of aquatic habitat (AqH) per continent.

	$Area_{AqH\ global}$ (km^2)	$Area_{AqH\ continent}$ (km^2)					
		North America	South America	Europe	Africa	Asia	Oceania
Lakes	3,193,000	1,429,422	127,144	224,387	302,235	1,092,572	17,240
Reservoirs	292,000	130,721	11,627	20,520	27,639	99,916	1,577
Rivers	433,250	193,955	17,252	30,446	41,010	148,248	2,339
Floodplain	3,215,000	1,005,367	559,161	91,206	460,939	1,001,859	96,468
Other wetlands	3,271,200	1,022,942	568,935	92,800	468,997	1,019,372	98,154

Table 2.—Summary of mean inland capture fisheries yields (kg/ha/year) by continent and water type ($Yield_{AqH\ continent}$). Where no data was available for aquatic habitat in specific continents (E) average values from similar habitats and continents have been used (see Methods). See Table A.1 for additional information on 95% confidence interval and references.

	$Yield_{AqH\ continent}$					
	North America	South America	Europe	Africa	Asia	Oceania
Lakes	2.8 (40)	54.9 (12)	13.0 (30)	73.0 (96)	156.1 (55)	50.1 (7)
Reservoirs	37.0 (4)	112.5 (74)	41.3 (8)	81.0 (85)	57.6 (116)	83.7 (E)
Rivers	12.4 (E)	12.4 (44)	39.3 (12)	30.7 (E)	48.9 (18)	30.7 (E)
Floodplain,	13.3 (E)	182.1 (6)	13.3 (E)	50.4 (26)	166.6 (52)	132.9 (E)
Other wetlands	6.0 (E)	59.8 (E)	6.0 (E)	3.1 (4)	116.6 (8)	59.9 (E)

The theoretical average global fisheries harvests (TFH_{Global}) was estimated at approximately 72 million metric tons (Figure 1A), with a 95% confidence range of 32,000,000–126,000,000 metric tons. The theoretical fisheries harvest per continent ($TFH_{Continent}$) was approximately: 3.1 million metric tons (North America), 14.4 million metric tons (South America), 0.67 million metric tons (Europe), 5.0 million metric tons (Africa), 46.9 million metric tons (Asia) and 2.0 million metric tons (Australia and Oceania) (Figure 1). Theoretical fisheries harvest per aquatic habitat type (Figure 1B) was greatest in floodplains (31.9 million metric tons) followed by lakes (20.7 million metric tons), other wetlands (16.7 million metric tons), reservoirs (1.5 million metric tons), and rivers and streams (1.2 million metric tons).

The global fish biomass (FB_{Global}) for lakes, reservoirs and rivers was estimated to be 28.3, 2.6, and 7.6 million metric tons, respectively. The global fish production (FP_{Global}) for lakes, reservoirs, and rivers was estimated to be 22.9, 2.1, and 10.6 million metric tons, respectively (Figure 2), based on the global mean fish biomass (mean FB_{Global}) and mean fish production (mean FP_{Global}) (Table 3). The theoretical fisheries harvest based on net primary production from lakes ($TFHL_{NPP}$) was determined to be 31.5 million metric tons.

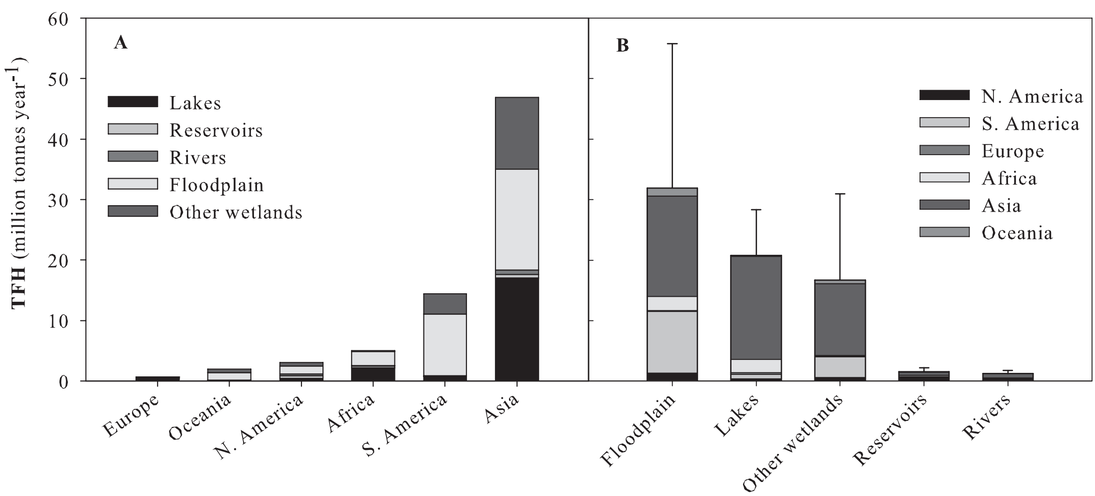

Figure 1.—Estimated theoretical annual inland capture fisheries harvest (TFH) **(A)** per continent and **(B)** per aquatic habitat. Error bars are $TFH_{Yield\ 95\%\ confidence\ interval}$.

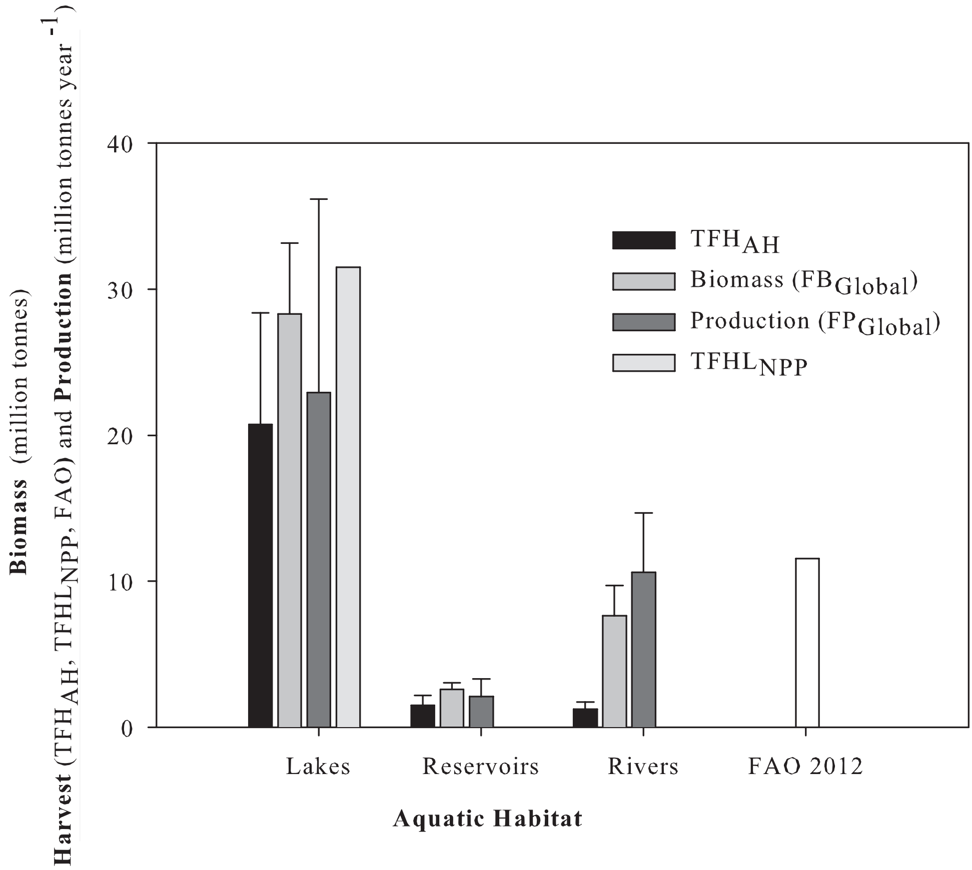

Figure 2.—Comparison of estimated global fish biomass (FB_{Global}) for lakes, reservoirs, and rivers; fish production (FP_{Global}) for lakes, reservoirs, and rivers; theoretical fish harvest (TFH); theoretical fisheries harvest in lakes based on net primary production ($TFHL_{NPP}$) displayed by aquatic habitat (AqH: lakes, reservoirs, rivers); and reported figures from the Food and Agriculture Organization of the United Nations for inland capture fisheries for 2012 (FAO 2012). Error bars are 95% confidence interval (CI) for FB_{Global} and FP_{Global} and $TFH_{AqH\ yield\ 95\%\ CI}$ for TFH^{AqH}.

Table 3.—Global mean freshwater fish biomass ($FB_{Global\ mean}$) and mean fish production ($FP_{Global\ mean}$) in lakes, reservoirs, and rivers with 95% confidence interval (CI). *n* = number of water bodies.

	$FB_{Global\ mean}$ (kg/ha)	±95% CI	$FP_{Global\ mean}$ (kg/ha/year)	±95% CI
Lakes and reservoirs[a]	88.7 (*n* = 160)	15.1	71.8 (*n* = 23)	41.4
Rivers[b]	176.0 (*n* = 95)	47.6	244.7 (*n* = 72)	94.2

[a] Downing et al. 1990; Randall et al. 1995; Bachmann et al. 1996; Sarvala et al. 1999; Emmerich et al. 2012; Samarasin et al. 2014.
[b] Randall et al. 1995; Kwak and Waters 1997; Formigo and Penczak 1999; Mazzoni and Lobo'n-Cervia 2000; Welcomme 2001.

Discussion

We estimated the global theoretical harvest of fish from all inland waters to be 72 million metric tons. Welcomme (2011b) estimated the potential harvest from only lakes to be 93 million metric tons using a similar estimate of global lake area (Downing et al. 2006). We estimated total harvest from lakes (TFH_{Lakes}) to be 20.7 million metric tons (Figures 1 and 2). The difference between the two analyses is due to the higher yield values used in the Welcomme's (2011b) analysis, especially for smaller size lakes that are often intensively managed by stocking, from where the majority of the harvest in Welcomme's analysis originated.

Our figure of approximately 5 million metric tons for theoretical harvest in Africa is higher than previous estimates. For Africa, as a whole, it was estimated that the inland waters had a potential harvest between 1.99 and 3.22 million metric tons (Vanden Bossche and Bernacsek 1990). This difference is probably because the total water area used for estimation was lower than the area used in our estimation. In addition, previous work estimated the potential harvest from African rivers to be 558,241 metric tons per year (Welcomme 1976). Our estimates from lakes, reservoirs, and rivers are based on a large collection on yield data, and hence, our confidence in these data is high. The level of harvest obtainable in different aquatic habitats is ultimately based on the diversity and stocks of wild fish species (biomass) and their annual productivity (Welcomme and Hagborg 1977; Christensen and Pauly 1993; Welcomme 2001). Our harvest estimates are compatible with independently derived estimates of fish biomass and fish production (Figure 2). However, the theoretical harvest assessments for floodplain and other wetlands are less robust and display large variation (Figure 1), with the exception of Asia where fish harvest from floodplains and rice fields are known to be common and several estimates of yield exist (Table 2). The basis for fish production is mainly primary production (Welcomme and Hagborg 1977), which is then either respired or consumed by higher trophic levels (Christensen and Pauly 1993). Our estimate for $TFHL_{NPP}$ of approximately 31 million metric tons of fisheries production from lakes (Figure 2) based on NPP is higher than the 95% confidence interval of the total fishery harvest from lakes (TFH_{Lakes}). Hence, our harvest estimate for lakes is reasonable (Christensen and Pauly 1993) and conservative compared to earlier global NPP assessments of Huston and Wolverton (2009) who reported a global NPP value of 4.3×10^{15} g C)/year. Compared to official reported inland capture fisheries catches (FAO 2014a, 2014c), our theoretical fisheries harvest (TFH) is higher for all continents and aquatic habitats (Figure 2); globally, the reported catches are 16% of TFH we calculated. At continent level, the largest differences (percentage) are found in Australia and Oceania, South America, and Asia. These differences could be an indication of low exploitation levels of the total area for Australia and Oceania. However, underestimation and underreporting of inland catch is a more likely explanation in South America and Asia (Coates 2002). To reach the estimated TFH of 72 million metric tons, all water bodies would need to be managed for fisheries harvest as this is potential yield.

The total area of aquatic habitat used in this assessment is more than double the value of 4,560,204 km^2 currently used by the Food and Agriculture Organization of the United Nations (FAO 2014b) for global assessments of inland water area. However, the application of new geographic information systems and satellite imagery has recently made it possible to make more accurate estimations of global water area (Verpoorter et al. 2012). The estimates we derived are in general agreement with other studies of specific aquatic habitats (e.g., inland water area in Africa [Jenness et al. 2007], global river area [Downing et al. 2012], global area of lakes and reservoirs [McDonald et al. 2012], global lake area [Verpoorter et al. 2014], global rice field area [Halwart and Gupta 2004], and estimates of global inland water area [MEA 2005; Fluet-Chouinard et al. 2015]). The global theoretical inland capture fisheries estimate of harvest could be improved by using satellite imagery to obtain more precise large-scale area measurements (Verpoorter et al. 2012; Fluet-Chouinard et al. 2015) and water quality (e.g., chlorophyll a) measurements (Deines et al. 2015) in fish harvest models.

In conclusion, we have provided an estimate of global theoretical annual inland capture fisheries harvest that is, on average, 6.5 times higher than the official catch data submitted to FAO. Thus, the potential monetary and social value of inland capture fisheries and their contribution to food security and livelihoods may be much higher than the officially reported harvest data suggest.

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Appendix A. Inland capture fisheries yields by continent and aquatic habitat

Table A.1.—Summary of mean inland capture fisheries yields (kg/ha/year) by continent and aquatic habitat ($\text{Yield}_{\text{AqH continent}}$). *n* denotes number of water bodies included, and where no data was available for aquatic habitat in specific continents (E), average values from similar habitats and continents have been used (see Method). 95% confidence interval, ±95% CI. References for the water bodies included in the analysis (References)

		$\text{Yield}_{\text{AqH continent}}$			
		n	Mean	±95% CI	References
North America	Lakes	40	2.8	0.9	1, 2, 3, 4, 5
	Reservoirs	4	37.0	36.9	6
	Rivers	E	12.4	3.5	
	Floodplain,	E	13.3	7.9	
	Other wetlands	E	6.0	5.1	
South America	Lakes	12	54.9	53.4	3, 7
	Reservoirs	74	112.5	23	6, 7
	Rivers	44	12.4	3.5	8, 9, 10, 11, 12, 13
	Floodplain	6	182.1	420.7	7, 10, 14, 15, 16
	Other wetlands	E	59.8	50.8	
Europe	Lakes	30	13.0	3.4	2, 3, 7, 17, 18, 19
	Reservoirs	8	41.3	21.6	6
	Rivers	12	39.3	15.9	6, 13, 20
	Floodplain	E	13.3	7.9	
	Other wetlands	E	6.0	5.1	
Africa	Lakes	96	73.0	14.8	2, 3, 7, 21, 22, 23, 24, 25, 26, 27
	Reservoirs	85	81.0	14.4	6, 7,
	Rivers	E	30.7	12.4	6, 7, 28, 29, 30, 31
	Floodplain	26	50.4	17	7, 32, 33, 34, 35, 36, 37, 38, 39
	Other wetlands	4	3.1	4.9	7
Asia	Lakes	55	156.1	57.3	2, 3, 4, 7, 40, 41, 42, 43, 44
	Reservoirs	116	57.6	9.4	6, 7, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58
	Rivers	18	48.9	21.2	6, 7, 41, 44, 46, 57, 58, 59
	Floodplain	52	166.6	38.7	6, 7, 41, 52, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70
	Other wetlands	8	116.6	98.7	7, 47, 61, 71, 72, 73, 74, 75
Oceania	Lakes	7	50.1	21	76
	Reservoirs	E	83.7	15.6	
	Rivers	E	30.7	12.4	
	Floodplain	E	132.9	79.1	
	Other wetlands	E	59.9	50.9	

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In the Frame: Modifying Photovoice for Improving Understanding of Gender in Fisheries and Aquaculture

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Abstract.—Understanding the role and value of small-scale fisheries to livelihoods and food security is a key challenge in conserving fishery resources. This is particularly true for small-scale inland fisheries, one of the most underreported and undervalued fisheries sectors that also increasingly faces environmental and societal change. Gender plays a central role in the different ways in which inland fisheries contribute to food and nutritional security in developing countries. The role of women in inland fisheries is significant, with millions of women contributing to dynamic capture fisheries and aquaculture supply chains. The role of women in inland fisheries, however, is less visible than the role of men and is often overlooked in policymaking processes. The need for participatory community-based approaches has been widely recognized in natural resource management literature as a means to capture people's perspectives and empower marginalized groups. The Photovoice method is increasingly used as a participatory tool in health, social, and environmental research, but has had little adoption in inland fisheries research to date. The aims of this paper are (1) to review and evaluate the effectiveness of an emerging participatory method, Photovoice; and (2) to present a modified Photovoice method, applicable to the context of small-scale fisheries, to advance understanding of gender and socioecological dimensions. We outline the strengths and limitations of the method and highlight that it can be used as a tool for triangulation of mixed research methods or independently. We argue that Photovoice, as a par-

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ticipatory tool in fisheries research, has the potential to provide rich, qualitative, context-specific, untapped sources of knowledge to advance fisheries research and management. The use of Photovoice in the context of small-scale inland fisheries and aquaculture research is a timely endeavor given heightened interest to obtain insights into the previously overlooked aspects of gender and the need for more policy relevant information.

Introduction

The role of women in the capture fisheries sector has traditionally been less visible with a long-standing assumption that the sector is dominated by men worldwide (Davis and Nadel-Klein 1992; Williams et al. 2004; Bennett 2005). This incorrect assumption has been reinforced by the exclusion of women from registering in the sector in some countries (HLPE 2014). Women and men, however, are increasingly viewed as both having an important role in fisheries and aquaculture worldwide (Allison and Ellis 2001; FAO 2006, 2012). For instance, a recent study by Mills et al. (2011) provided the first known estimate of gender characteristics in the capture fisheries sector worldwide. The authors estimated that 50% of the 120 million fishers employed in capture fisheries were women, with the vast majority employed in postharvest activities (such as processing and packaging) of small-scale fisheries in developing countries. In terms of the aquaculture sector, comparable estimates about gender characteristics to those for capture fisheries do not exist. However, entry into aquaculture is known to have fewer gender barriers than capture fisheries, resulting in more women actively participating in diverse aquaculture activities (including preharvest, harvest, and postharvest activities; Weeratunge et al. 2010; Williams et al. 2012a).

As a result of limited gender data in fisheries and aquaculture, little policy attention has traditionally been given to the gender dimension in these sectors. Nevertheless, there have been some recent promising attempts to promote a more holistic view of fisheries and aquaculture in policy, including greater attention to gender (FAO 2012, 2015; Williams et al. 2012b). For example, the Food and Agriculture Organization of the United Nations-led Voluntary International Guidelines on Securing Sustainable Small-Scale Fisheries in the Context of Food Security and Poverty Eradication (FAO 2015) recognizes the important role of gender in relation to equitable access to resources, decent work, management voice, and activities, among others. The expansion of fisheries policy discourses to include a more holistic approach to fisheries management is resulting in an increasing need to include gender in the understanding of both social (Weeratunge et al. 2010; Williams 2010; Harper et al. 2013; HLPE 2014) and ecological (Kleiber et al. 2015) systems. For example, a recent review by the High Level Panel of Experts on Food Security and Nutrition (HLPE 2014) highlights that gender can influence the different mechanisms that determine access to fish and nutrition, both within the general population (as consumers) and population groups directly involved along supply chains (as producers, processors, and traders). Women can also play a dominant role in prioritizing food for household members (Quisumbing et al. 1995; Porter 2012) and have been identified as providing an untapped potential source of valuable local ecological knowledge for improved fisheries management (Kleiber et al. 2015).

A gap in understanding gender patterns in fisheries and aquaculture, however, continues to be widely reported in the literature (FAO 2009, 2014; Béné et al. 2016). More specifically, a dearth of gender-disaggregated data in the fisheries and aquaculture sectors exists, which limits the accurate understanding of how these sectors function (Geheb et al. 2008; Harper et al. 2013). A recent review by Kleiber et al. (2015) highlights that biases in sampling methods and research have led to significant gaps in gender-relevant data in small-scale fisheries. This paper aims to address this information gap by (1) reviewing and evaluating the effectiveness of Photovoice as an emerging method in community-based participatory research, and (2) presenting a modified Photovoice method, applicable to the context of small-scale fisheries, to advance understanding of gender dimensions and socioecological aspects of fisheries and aquaculture. This review aims to connect thinking about gender dimensions in fisheries and aquaculture with respect to (1) the roles and contributions of women and men, (2) the varying socioeconomic benefits they obtain, (3) the constraints they experience, and (4) the characteristics of the fisheries. We argue that Photovoice serves as a lens to provide a richer understanding of socioecological dimensions of small-scale fisheries and aquaculture.

Photovoice—Addressing the Need for Gender-Sensitive Methodological Approaches in Fisheries

The use of participatory approaches in research have arisen to provide a more in-depth analysis of the views of local people that could otherwise not be achieved through standard social methods such as questionnaire surveys (Chambers 1992; Pretty et al. 1995; Schreckenberg et al. 2010). The application of participatory approaches, during the past two decades, has increased in literature associated with the management of natural resources. The drive to include a more participatory approach to fisheries research has largely arisen from a number of perspectives, including the move towards interactive governance and participation in fisheries management, as well as the importance of collaborative learning in small-scale fisheries (Wiber et al. 2009; Kolding et al. 2014; FAO 2015).

Participatory research is described as having considerable, yet often unrealized, potential in advancing fisheries research globally (Wiber et al. 2009). In fisheries literature, a range of participatory methodologies have been implemented that have been classified into four models as described by Hoefnagel et al. (2006):

1. Deference model—requiring the role of fishers as research assistants (e.g., Ticheler et al. 1998);
2. Experience-based knowledge model—emphasizing fishers' observations as a supplement to research-based knowledge (e.g., Wilson et al. 2006);
3. Competing constructions model—understanding differences in stakeholder objectives leading to biases in presenting knowledge (e.g., Finlayson. 1994); and
4. Community science model—promoting collaborative fisheries science through incorporation of models 1–3 with effective communication.

Hoefnagel et al. (2006) suggests that the ideal method for participatory fisheries research is the community science model of interaction, which provides a more collaborative and holistic approach to the development of research by scientists and fishers. Although a range of qualitative and quantitative methods have been applied in fisheries and aquaculture research, flexible and creative tools have been called for to (1) capture the complexity of context specific factors (Harper et al. 2013; Kleiber et al. 2015), (2) produce policy relevant results (Wiber et al. 2004), and (3) integrate the views and realities of fishers within the management process (Krause et al. 2015).

One innovative community-based participatory research method that has been increasingly reported in the literature as having the potential to offer considerable promise for use with marginalized, often neglected, illiterate populations is the Photovoice process (hereafter referred to as Photovoice). Photovoice is a unique form of community-based participatory research founded on the principles of feminist theory, constructivism, and documentary photography. The originators, Wang and Burris (1997:369), describe Photovoice as a process by which ‘‘people can identify, represent and enhance their community through a specific photographic technique.” The Photovoice process involves providing participants with the opportunity to take photographs of a particular community issue that are then used to facilitate participants' critical reflections. Throughout the process, participants have control over what they document, what conclusions to report, and how to catalyze change in their communities (Wang and Burris 1997). The Photovoice process typically comprises several stages, including recruitment and training, photography assignment, group or individual selection and discussion of photographs, coding of themes from the photographs, and a final phase to create research outputs (Wang et al. 1997; Castleden et al. 2008). The theoretical principles underpin the overarching goals of Photovoice, which are "(1) to enable people to record and reflect their community's strengths and concerns; (2) to promote critical discussion and knowledge about important community issues through large and small group discussions of photographs; and (3) to reach policymakers" (Wang and Burris 1997). At its center, Photovoice seeks to make community needs more visible and to empower illiterate participants to advocate for changes at the individual, community, and policy levels (Wang and Burris 1997). As a participatory method, Photovoice offers considerable promise for use in working with vulnerable, uneducated, and marginalized populations, such as women in the fisheries sector, due to its flexibility in design and use of photography as a means of language. Photovoice uses the means of photography to capture community issues and interests through a research process directed towards equal sharing of research decisions and empowerment of participants. The participatory method has proven to be successful in capturing complex context specific issues, as well as producing high-quality, richer, and policy-relevant research (Bennett and Dearden 2013; Kong et al. 2015). Furthermore, by facilitating closer participant–researcher interactions, Photovoice provides a promising tool in meeting the desired community science model of interaction in participatory fisheries research. Last, Photovoice may be effective in gathering sensitive gender information, which, as highlighted by Williams et al. (2012a), is best achieved by gathering data about "gender roles and contributions… within their context and characterized with respect to economic, social and individual assets and people's needs."

Review of Photovoice in Natural Resources Studies

A comprehensive overview of the application of Photovoice in public health and related disciplines can be found in the work by Hergenrather et al. (2009) and Catalani and Minkler (2010). Given the increasing application of Photovoice within the field of natural resource management, a comprehensive literature review was carried out to evaluate the use of Photovoice within this broad area of research. The literature review included the search terms "Photovoice," "Photo-voice," and "Photo voice" in two main search engine domains: Science Direct and Web of Knowledge. The initial search using these key words resulted in 113 peer-reviewed articles. After reviewing all abstracts and removing those that did not lie within natural resource management literature, a total of 10 studies were identified for evaluation (Bosak 2008; Castleden et al. 2008; Baldwin and Chandler 2010; Beh 2011; Tanjasiri et al. 2011; Berbés-Blázquez 2012; Bennett and Dearden 2013; Bisung et al. 2015; Crabtree and Braun 2015; Kong et al. 2015). From this evaluation and building on work by Palibroda et al. (2009), a summary of the advantages and limitations of applying the Photovoice method was drawn (see Table 1). The use of Photovoice in fisheries and aquaculture research has, to our knowledge, only been applied to a small number of studies, with only one reported study carried out in a developing country and no reported studies within the context of small-scale or inland fisheries (Bennett and Dearden 2013).

Overall, the evaluation reveals growing recognition that Photovoice provides a powerful tool in addressing complex social-ecological issues and in capturing unique perspectives of marginalized populations in diverse settings (Berbés-Blázquez 2012; Bennett and Dearden 2013; Kong et al. 2015). In addition, a few studies highlight that Photovoice generated more enriched data and opportunities for mutual

Table 1.—Summary of advantages and limitations associated with the Photovoice methodology. (Adapted from Palibroda et al. 2009).

Actor(s)	Advantages	Limitations
Participants	Develop skills in reflecting on and understanding community functioning. Accessibility and ease of use of cameras, particularly for vulnerable people (e.g., elderly, illiterate, women). Have improved self-esteem from skill building, competently taking photographs, and participation. Participate in decision-making and problem-solving skills, collaboration, and consensus through group process. The opportunity for participant views to be integrated into decision-making processes.	The time committment may be taxing for some individuals, particularly if the project continues over several weeks. The novelty of cameras by inexperienced participants may result in the capturing of nonrelated project photographs. The participants might have trouble presenting complex or abstract ideas through their photographs. The close examination of an issue of concern can cause negative feelings.
Researcher/ facilitator	The active participation of community members as coresearchers provides a level of expertise and knowing that would otherwise not be accessible. Photovoice creates a flexible power-sharing form of research that differs from traditional research methods. "A picture is worth a thousand words." Photovoice provides richer, varied, and unpredictable data over and above traditional research methods. Photovoice emphasizes empowerment and offers a nonoppressive way of engaging marginalized individuals and groups to gather their own research information.	Time and budget can be a concern. The loss of, or damage to, cameras is a possible risk. Photovoice adopts a snapshot approach and can lead to omission of community issues or interests. A wide range of researcher skills is necessary to complete the Photovoice process. For some researchers, community work may be a new and unfamiliar experience. The dissemination of outputs to policy makers requires time and careful planning.
Community	The opportunity for community growth and improvement, based on the activities of participants. When community members gain an increased understanding and awareness of community strengths and struggles, they are better equipped to get involved and work towards change.	The actual outcomes of the Photovoice activities may not be as significant as expected by community members. Influencing policy change requires long-term periods for effective monitoring and evaluation

learning between researcher and participant than traditional research methods such as semi-structured interviews, and it is a valuable tool for triangulation of mixed methods (Baldwin and Chandler 2010; Bennett and Dearden 2013; Kong et al. 2015).

Modified Photovoice Methodology for Fisheries and Aquaculture Research

Participatory research tools must be adaptable to a community's particular circumstances and context. It is not surprising, therefore, to find that during the previous decade, Photovoice has evolved into a more flexible participatory methodology from Wang and Burris's (1997) original static description. As evident from the review presented here, Photovoice has increasingly been modified and applied to fit a diverse set of cultures, research topics, and geographical contexts (Castleden et al. 2008; Bennett and Dearden et al. 2013).

Although many successful modifications of the Photovoice method exist, the development of an improved version of the Photovoice process was deemed necessary within this review to address: (1) inherent challenges in participatory small-scale fisheries research, and (2) limitations reported with applying Photovoice.

Standard stages involved in the Photovoice process were modified based on standard steps from Wang and Burris (1997) and on best practices of steps taken from studies (see Appendix A). Taking into account these modifications and steps suggested by other studies (Castleden et al. 2008; Bennett and Dearden 2013), an improved eight-step Photovoice process was developed, as described below.

1. Community connection and consultation—building trust;
2. Planning—funding, logistics, ethics.
3. Recruitment and group training session—participant identification, introduction, camera distribution, and instructions;
4. Photography assignment and camera collection—periodic check-in on participants, camera collection, and development;
5. Discussion of photographs through individual interviews—development of narratives through critical reflection on images;
6. Data analysis—coding of main topics and themes;
7. Group discussion—verification of key messages, identification of dissemination activities, and evaluation of the Photovoice experience; and
8. Dissemination—communication of out comes to targeted audiences.

Changes were made to the recruitment, training session, interview format, length of study, photography assignment, and evaluation stages. The changes address limitations outlined in Table 1.

The modified process serves as a flexible tool for application within the context of small-scale fisheries, and to be adaptable to fit the particular needs, budget, and timescale of a research project. Box 1 outlines in detail the steps and proposes questions that aim to understand socioecological aspects of small-scale fisheries through a gender approach.

Conclusion

Photovoice has increasingly been modified and applied to fit a diverse set of cultures, research topics, and geographical contexts (Castleden et al. 2008; Bennett and Dearden et al. 2013). Limitations have been reported that are deemed manageable, and the strength of Photovoice as a participatory tool providing rich qualitative and context specific data has been highlighted by several studies. A modified version of Photovoice is presented, which addresses limitations, builds on Wang and Burris (1997) and best practices applied and can be taken forward in the context of small-scale fisheries in a gender-sensitive approach. Through the lens of photography, the method serves to portray context specific real-life imagery of community issues through the unique perspectives of participants over and above what other traditional methods can capture (Bennett and Dearden 2013; Kong et al. 2015). In addition, the Photovoice process allows marginalized peoples to become empowered and more able to advocate for change at the individual, community, and policy levels (Wang et al. 1998). This paper describes a modified and flexible Photovoice method applicable to understanding rich context-specific social and ecological information in diverse small-scale fisheries contexts. This improved Photovoice method, applicable to small-scale fisheries, contributes to the growing methodological literature in fishery research and provides a timely endeavor to advancing wider social-ecological understandings of small-scale and inland sectors.

Box 1. Step-by-Step Guide to the Photovoice Methodology

Stage 1. Community connection and consultation: This stage requires sufficient time and effort to establish rapport and build trust with fishers to retain high quality participant participation and overcome dilemmas inherent in fisher–researcher relations. Prolonged immersion in the field, collaboration with local experts, and transparent communication with community members are recommended.

Stage 2. Planning a Photovoice project: The following considerations, in addition to generic project planning prerequisites, should be addressed:

1. Budget: When working in often remote fishing communities, additional travel costs to and from case study sites, risks of camera theft or damage, and transport to an identified photograph development store should be factored into project costs.
2. Logistics and administration: The development of consent forms, transport arrangements, and identification of where to develop photographs need to be arranged early on in the project.
3. Equipment: Funding might be a deciding factor regarding the selection of camera for the project. Low-cost disposable cameras that are waterproof are recommended, particularly given the defined cap of images making data and costs more manageable.
4. Ethical approval should be obtained from a competent organisation/institution and full consent must be obtained from participants.

Stage 3. Recruitment and training: Participants should be recruited via a training workshop. As a rule of thumb, Wang and Burris (1997) recommend to recruit a group of 7 to 10 people to participate in the Photovoice method via a combination of snowball and purposive sampling. Purposive sampling is a form of nonprobability sampling that allows for the selection of individuals based upon a variety of criteria determined by the research study of interest. Snowball sampling is a nonprobability sampling process that is used to identify research subjects through an initial contact who suggests possible participants for the study. A mix of male and female participants should be recruited to allow for effective gender analysis. Once participants have agreed to participate in the study, a group training session (estimated 2 h) should be organised and cover (1) research aims, timeline, and benefits of participation; (2) ethical considerations in research using photography; (3) safety concerns; (4) technical instructions regarding how to use the disposable cameras; and (5) details of the camera assignment. Informed consent should be obtained from all participants, verbally via use of a Dictaphone or in writing. In the context of small-scale fisheries, training may be facilitated by a translator, and in these situations, it is recommended that guidance be provided to the translator in advance of the workshop. Instructions should be presented orally and/or with visual aids such as a leaflet to help guide potential illiterate or vulnerable older/younger participants. A dummy camera can be used to help instruct participants on how to use the camera. At the end of the training session, each participant should be given a camera with a unique tag ID for data ownership control. The camera assignment stage is flexible and participants should be asked to take pictures in accordance with questions that reflect the aims of the project. Within the context of this review, the following questions were proposed for the context of small-scale fisheries to obtain deeper insights into the fisheries socioecological aspects:

Box continues

Box 1. Continued

1. What activities do you carry out in relation to fish farming or capture fisheries?
2. What benefits do you receive from fish farming or capture fisheries?
3. What challenges do you experience in fish farming or capture fisheries?

Stage 4. Photography assignment and collection: Participants are to be left with one camera each for a recommended period of 1 week. During this time, researchers should periodically check in on participants to ensure that cameras have not been stolen or damaged and that participants are content with the task (either via telephone or face to face). After 1 week, cameras should be collected and developed at a local photography store.

Stage 5. Discuss photographs through individual interviews: After the photographs have been printed, in-depth individual interviews should be conducted to learn the narratives behind photographs. Interviews should be recorded with permission for further analysis and to allow cross-checking of narratives. During discussions, printed photographs should be displayed and a subset of the most important pictures should be selected by the participant in accordance with each of the three research questions posed. A variety of techniques can then be used to elicit responses to questions about the photographs and to learn the narratives behind the photographs (Palibrodo et al. 2009). Researchers can choose a technique that best fits their project. Within the context of this review, a modified version of Wang et al.'s (1998) mnemonic SHOWED line of questioning was developed as follows:

1. What is in the picture?
2. Why did you take the picture?
3. Why did you select this picture over the others?
4. What would you like to tell to others with this picture?
5. Why would it be important to give this message to others?
6. Is there any other information you were unable to capture during the exercise that you would like to share?

The length of the interview will be subject to group size and it is recommended that the researcher sets aside a minimum of 3 hours.

Stage 6. Data analysis: Transcript data obtained from individual interviews can be analysed in a similar way to other qualitative data, via codifying, and exploring, formulating, and interpreting themes. To minimize the time required from participants and expenses incurred from site visits, this review recommends analysis to be carried out by the researcher and later verified by participants in stage 7.

Stage 7. Presentation of findings and discussion of outcomes: The aims of the final group session should be to (1) share narratives and verify key messages, (2) discuss dissemination activities, and (3) capture group perspective on the Photovoice experience. The group interviews should be recorded with permission to assist further analysis. This stage is flexible and should be tailored to meet goals of a given project.

Box continues

Box 1. Continued

Stage 8. Dissemination: Many projects have included an action phase to share their photographs and findings via the development of books, exhibitions, targeted workshops or forums for broader community and policy awareness. This emphasis on involving policymakers and broader community activities has been a part of Wang et al.'s (1997) recommendations for best practices. This stage is flexible and should be driven by outcomes from stage 7, as well as the goals of a given project.

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Appendix A. Photovoice Review

Table A.1.—A summary of photovoice studies within the broad field of natural resource management. (Adapted from Hergenrather et al 2009).

Author and year	Topic	Context	Number of participants	Participant description	Length of study	Discussion trigger	Data analysis improvement	Outcomes
Bosak 2008	Biodiversity conservation 10 villagers	India, Garwal Himalayas	10 villagers from eight communities (7 men and 3 women)	Individual, semistructured interviews and group discussion	Unclear. Less than 1 month.	Facilitator questions	Author-driven based on content analysis of the images and identification of broad themes. Further review of interviews to identify/match themes.	Photographs
Castelden et al. 2008	Natural resource management, indigenous knowledge	Canada, Vancouver	40 (25 male, 15 female)	Individual, semistructured interviews	6 months	Facilitator questions	Participant selection. identification of themes through coding.	Photographs, interview transcripts and follow-up community dinners, newsletters, posters.
Baldwin and Chandler 2010	Climate change and coastal	Australia	16 participants (divided into 3 groups)	Group discussions and captions	1 month	Facilitator questions	Participant selection and discussion of emerging themes.	Photographs, captions, exhibition, and online Web gallery.
Beh 2011	Conservation education	Kenya	26 participants (stakeholders within one district)	Individual, semistructured interivews	7 months	Facilitator questions	Participant selection and discussion of emerging themes (coding). In addition, further identification of themes by the lead author.	Photographs, interview transcripts, and gallery exhibits.
Berbés-Blázquez 2012	Ecosystem services	Costa Rica, pineapple agriculture	12 participants divided into small groups of 3–4	A modified transect walk, followed by group discussions	5 months (entire wider project)	SHOWED[a]	Participant selection and discussion of emerging themes. In addition, identification of themes by the lead author according to the millennium assessment framework.	Photographs, interview transcripts.

Appendix A. Continued

Table A.1.—Continued.

Author and year	Topic	Context	Number of participants	Participant description	Length of study	Discussion trigger	Data analysis improvement	Outcomes
Bennett and Dearden 2013	Social and ecological change	Andaman coast of Thailand, coastal/ marine communities	20 from two villages (9 and 11, respectively)	Individual semistructured interviews, group discussions and follow-up community meeting	2–3 months (entire wider project)	Facilitator questions	Participant selection and discussion of emerging themes. In addition, further identification of of themes by the lead author.	Photographs, interview transcripts, books (online and hard copies).
Bisung et a2015	Water–health nexus	Kenya, lakeshore community	8 participants (all females) from one community	Individual semistructured interviews, group discussions and follow-up community meeting	3 months.	Facilitator questions	Participant selection. Author identification of themes with the use of NVivo.	Photographs, interview transcripts, and follow-up workshop/ community meeting.
Crabtree and Braun 2015	Natural disaster management	Hawaii	Unclear, one community	Unknown	Unknown	Unknown	Unknown	Unknown
Kong et al. 2015	Environmental sciences, land management	South Africa	25 participants from two study sites (14 and 11)	Individual semistructured interviews and group discussion	Unclear, estimated 1 week.	Facilitator questions	Participant selection. Author identification of themes through coding in NVivo 10.	Photographs, interview transcripts, and follow-up community meeting.
Tanjasiri et al. 2015	Environmental sciences, tobacco control	USA, California and Washington (Asian American and Pacific Islander communities)	32 participants from four community agencies	Individual semistructured interviews and follow-up workshop/ stakeholder meeting	Unclear. Overall project total, 3 years	SHOWED[a]	Participant selection. Author identification of themes.	Photographs, interview transcripts and follow-up workshop/ stakeholder meeting

[a] Wang et al. (1998) recommends facilitating a photovoice discussion by the mnemonic SHOWED, which stands for ‘‘What do you *See* here? What is really *Happening* here? How does this relate to *Our* lives? Why does this concern or strength *Exist*? What can we *Do* about this?’

Biological Assessment by a Fish-Based Index of Biotic Integrity for Turkish Inland Waters

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Abstract.—The biological assessment of inland waters using ecological criteria is becoming more important due to the need to evaluate and monitor aquatic environments that are under heavy environmental stress. Turkey has been trying to develop a model to understand its inland waters in terms of the European Water Framework Directive's (WFD) European fish index (EFI). The EFI is derived from assessment of five biological elements. The EFI is inappropriate for the conditions in Turkish inland waters; thus, the present study developed a fish-based index of biotic integrity for Turkey (FIBI-TR) as a suggestion. To assess the adequacy of the FIBI-TR, this study gathers field data in two selected basins in 2013 and 2014 according to WFD criteria for biological elements and physicochemical parameters, simultaneously. The FIBI-TR was then compared to the scores derived from the WFD score, which was a cumulative score for all related biological elements, and with other frequently used indices such as the Water Pollution Control Directive and trophic state index. Based on these data, the FIBI-TR seems to be congruent with cumulative WFD scores. However, the FIBI-TR does not agree with other indices based on physicochemical parameters. Detailed research is needed if WFD is to be adapted for Turkey through FIBI-TR.

Introduction

Turkey has been implementing the Water Framework Directive (WFD) as part of a process to apply the European Union's directives for eventual membership. First attempts in implementing this directive go back to 2002 when a preliminary project was conducted in cooperation with Netherlands, France, and Spain. Since then, monitoring of several basins had been completed while many projects supported by the Republic of Turkey Ministry of Forestry and Water Affairs, General Directorate of Water Management are still ongoing (Alka 2013a, 2013b; Cınar 2013a, 2013b; Artek 2015a, 2015b, 2015c; Segal 2015a, 2015b).

Assessment of the ecological status of inland waters consists of five biological elements: fish, benthic invertebrates, phytoplank-

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ton, phytobenthos, and macrophytes. Among these, fish fauna assessment is relatively easy (sampling, identification, etc.) and is highly indicative of any ecological degradation. For this purpose, a European fish index (EFI) was developed as an output of the Fame and EFI+ projects (Fame Consortium 2004; EFI+ Consortium 2009). It is impossible for Turkey to implement EFI, which is shared by several European countries, because it is not a partner of the FAME project and the related ecoregion is not defined. In order to develop a regional index, a typology of the water resources was defined and its faunal composition is under investigation.

The aim of this study is to develop a fish-based index of biotic integrity for Turkey (FIBI-TR), with metrics based on Karr (1981), and to evaluate its assessment capability. For this purpose, calculated FIBI-TR scores are first compared with the cumulative WFD score acquired by assessment of the five biological elements. All related biological elements (macroinvertebrates, fish, phytoplankton, phytobenthos, and macrophytes) were assessed for each locality and a final WFD score was determined according to the "one-out, all-out" principle and the arithmetic mean of the scores of these biological elements. Second, the FIBI-TR score is compared with other frequently used indices, such as the Water Pollution Control Directive water quality classes (WPCD 2004) and the trophic state index (Carlson 1977) in order to demonstrate their similarities and differences.

Methods

Field studies were conducted in May 2013 for the Akarçay basin (AB) and in May 2014 for the Küçük Menderes basin (KM) (Figure 1). Sampling of biological elements was conducted simultaneously with that of the physicochemical parameters of the water column (Alka 2013a; Segal 2015a).

Fish sampling was conducted according to WFD criteria, using electrofishing in rivers (CEN 2003a) and with multi-mesh gill nets in lakes (CEN 2003b). In lake sampling, some minor adjustments were made based on the European Standard EN 14757. These adjustments reduce the number of multi-mesh gill nets in order to avoid pressure on protected species, using larger mesh sizes (70, 90, and 110 mm) for catching large water column species and using fyke nets for catching the large benthic fish species, which were unable to be caught with multi-mesh nets according to EN 14962 (CEN 2003c; Šmejkal et al. 2015).

Ten sampling localities were selected where there was enough preexisting data

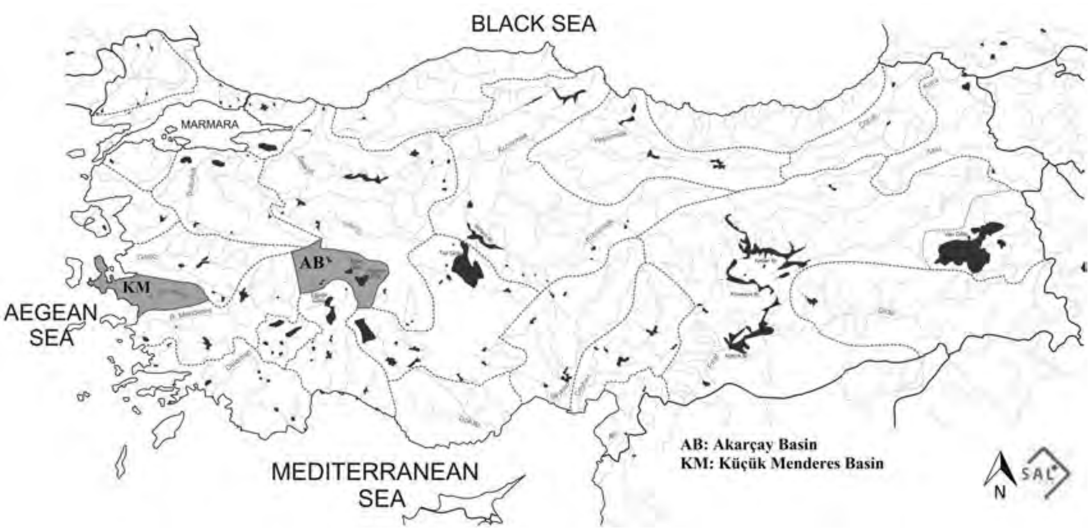

Figure 1.—Selected basins for the sampling.

about the fish fauna. Anthropogenic effects and reference conditions were taken into account while selecting the localities.

The FIBI-TR developed is a multimetric index based on reference condition criteria and was calculated as described by Karr (1981), Karr et al. (1986), and Kestemont and Goffaux (2002). Thirteen metrics were defined and each was given points from 1 (worst ecological condition) to 5 (best ecological condition). The FIBI-TR metrics and their expected impacts are summarized in Table 1.

All metric scores are summed into cumulative FIBI-TR score by locality. These scores and their corresponding ecological statuses are given in Table 2. For comparison with other indices, FIBI-TR scores are classified from 1 (bad ecological status) to 5 (corresponding to a very good ecological status).

Four parameters that are related to the trophic state of the water column (dissolved oxygen, pH, total phosphorus, and total nitrogen) were selected from Water Pollution Control Directorate (WPCD) water quality classes, and sampling stations were classified according to the values given in Table 3. Values range from 1 to 4, with class 1 representing the best water quality and class 4 representing the worst. Sampling localities were classified according to the "one-out, all-out" principle (i.e., the water body's final ecological status is determined by the worst scored biological element) for comparison with WFD scores.

Trophic state index (TSI; Carlson 1977); TSI Secchi depth, and TSI total phosphorus were calculated according to simplified equations given below (Carlson and Simpson 1996). Trophic state index values then turned to quality evaluation values as described by Sulis et al. 2014.

$$TSI_{\text{Secchi depth}} = 60 - 14.41 \ln_{\text{Secchi depth}}$$

$$TSI_{\text{Total phosphorus}} = 14.42 \ln_{\text{Total phosphorus}} + 4.15$$

FIBI-TR, WPCD water quality classes, TSI values, and WFD results were calculated using the same database.

Results

Results obtained from field studies in the Akarçay (Alka 2013a) and Küçük Menderes (Segal 2015a) basins are summarized in Table 4. Water Framework Directive results are given in the first three columns. The WFD column represents the status of the locality according to the "one-out, all-out" principle, whereas the mean column is the arithmetic mean of values of all five (or four, depending on sampling site) biological elements.

Table I.—FIBI-TR (fish-based index of biotic integrity for Turkey) metrics and expected impacts.

Category	Metric	With increase in degradation
Species composition	1. Number of native species	Expected to decline
	2. Percentage of alien species	Expected to increase
Tolerance	3. Number of intolerant species	Expected to decline
	4. Percentage of tolerant species	Expected to increase
Habitat diversity	5. Number of species rather than benthic ones	Expected to decline
	6. Number of benthic species	Expected to decline
Breeding habitat diversity	7. Percentage of phythophilic species	Expected to increase
	8. Percentage of lithophilic species	Expected to decline
Trophic state diversity	9. Percentage of omnivorous species	Expected to increase
	10. Percentage of carnivorous species	Expected to decline
Biodiversity indices	11. Shannon–Wiener diversity indices	Expected to decline
Abundance	12. Number per unit effort (NPUE; 1,000)	Expected to decline
	13. Catch per unit effort (CPUE; kg)	Expected to decline

Table 2.—FIBI-TR (fish-based index of biotic integrity for Turkey) scores and Water Framework Directive (WFD) value.

FIBI-TR score	WFD ecological status
1–13	Bad (1)
14–26	Weak (2)
27–39	Fair (3)
40–53	Good (4)
54–65	Very good (5)

Comparisons between WFD and FIBI-TR scores were made using the arithmetic mean of biological elements because when the "one-out, all-out" principle is applied, single biological element can cause the ecological status of the water body to decrease dramatically. One example is Streams AB1 and AB3 where the FIBI-TR suggests a fair (3) status whereas the WFD score suggests a poor (1) ecological situation. For these localities, the mean value of all biological elements is classified as weak (2), although many of the biological elements have better ecological statuses.

WFD-mean, which is the mean of all biological element index results, and FIBI-TR scores for two of the lakes are identical, whereas two of them (Lake AB01 and Lake KM02) differ by one degree. Similarly, WFD-mean and FIBI-TR scores for three of the streams are identical, whereas Streams AB01, AB03, and AB04 differ by one degree. FIBI-TR scores for Streams AB01 and AB03 suggest a better ecological status (fair), whereas the WFD-mean scores represent a poor status.

Within WPCD, dissolved oxygen and pH results are not consistent with phosphorus and nitrogen parameters. However, results for the latter, total phosphorus (TP) and total kjeldahl nitrogen (TKN), seem to be consistent with each other. When we compare these two parameters (TP and TKN), there are inconsistencies between the WFD and FIBI-TR scores. Localities like Lake AB01, Stream KM01, and Stream KM02 show similar TP and TKN scores, indicating bad quality (3–4), whereas their WFD and FIBI-TR scores vary from bad quality to good (1–4).

Trophic state index results for Lake KM1, Lake KM2, Lake KM3, and Lake AB1 agree relatively well with FIBI-TR. Trophic state index assessments appear more reasonable than WPCD to evaluate these lake ecosystems.

There seem to be some similarities between WPCD and TSI values. Sample size was not large enough for a clear statistical evaluation for this assessment; however, the tendency of these indices to support each other seems promising. As a result, the FIBI-TR developed seems to be in agreement with the cumulative WFD score but disagrees with the TSI and WPCD indices, which are based on physicochemical parameters. However, as the database grows, we believe parameters listed under these indices can be incorporated into the FIBI-TR.

Discussion

The WFD's EFI is shared by many countries; however, due to adaptation problems, some Mediterranean countries are unable to use it. Therefore, the index of biotic integrity of Catalonia (IBICAT) has been developed for Catalonia in Spain (Sostoa et al. 2004, cited by Segurado et al. 2014); IBI-Jucar has been developed for the Jucar River basin in Spain (Aparicio et al. 2011); two separate indices have been developed for the Guadiana basin, one for Portugal (Magalhães et al. 2008) and the other for

Table 3.—Water Pollution Control Directive water quality classes (WPCD 2004).

	Water quality class			
Parameters	1	2	3	4
pH	6.5-8.5	6.5–8.5	6.0–9.0	<6.0 to >9.0
Dissolved oxygen (mg/L)	8	6	3	<3
Total phosphorus (mg/L)	0.02	0.16	0.65	>0.65
Total kjeldahl nitrogen (mg/L)	0.5	1.5	5	>5

Table 4.—Locality index results (Alka 2013a; Segal 2015a). WFD = Water Framework Directive; FIBI-TR = fish-based index of biotic integrity for Turkey; DO = dissolved oxygen; TP = total phosphorus; TKN = total kjeldahl nitrogen; SD = Secchi depth.

	Water Framework Directive (1 = bad status, 5 = good status)		Water Pollution Control Directive (1 = good status, 4 = bad status)						Trophic state index (1 = good status, 5 = bad status	
Locality	WFD	Mean[a]	FIBI-TR	DO	pH	TP	TKN	One out, all out	SD	TP
Lake KM01	3	3	3	1	1–2	2	1	2	3	1
Lake KM02	2	3	2	1	1–2	3	2	3	5	3
Lake KM03	1	2	2	1	1–2	3	1	3	3	3
Lake AB01	2	3	2	1	4	4	3	4	5	5
Stream KM01	1	1	1	2	1–2	4	3	4	–	–
Stream KM02	3	4	4	1	1–2	3	4	4	–	–
Stream AB01	1	2	3	1	4	2	2	4	–	–
Stream AB02	2	3	3	1	1–2	2	3	3	–	–
Stream AB03	1	2	3	2	1–2	3	2	3	–	–
Stream AB04	2	3	2	1	3	2	2	3	–	–

[a] The arithmetic mean of all WFD biological element values.

Spain (Hermoso et al. 2010); and F-IBIP has been developed for Portugal (INAG and AFN 2012, cited by Segurado et al. 2014). All these indices have been improved to solve application problems of the WFD's EFI. Implementation of the EFI in Turkey is also problematic, experiencing problems similar to those these in other Mediterranean countries. Turkey has a high diversity of fish and habitats and a high number of endemic fish species (Kuru et al. 2014). The EFI+ was developed for 15 European countries (EFI+ Consortium 2009) and did not consider other countries, and also their ecoregions, in Europe, such as Turkey.

The WFD can be adapted for Turkey through FIBI-TR; however, the application of the FIBI-TR must address some challenges that are described below along with some possible solutions.

1. Turkey's inland water resources vary greatly in terms of water quality, trophic status, typology, altitude, climate, ecosystem diversity, and species diversity. A total of 25 basins, including many subbasins with different biogeographical histories, have been identified. A reference condition criteria needs to be applied separately for each basin, such as those presented here for the Akarçay and Küçük Menderes basins. All the efforts concerning FIBI-TR need to be followed by a national calibration process.
2. Long-term historical data are insufficient or are not available in many inland water basins, especially for fish species. The literature on the fish fauna generally lacks information on geological position, and this needs to be determined and digitized.
3. Because there is no detailed fish distribution database and bioecological information of the fish species is generally lacking, especially for endemic species, reference conditions are hypothetical. Bioecological information about these species, which are needed for the metrics, needs to be determined and published as soon as possible.
4. Fish, which represent the top level of the aquatic trophic chain and thus have the potential of integrative indication of biological change, also show a wide range of responses to different impacts. But individual and population based responses of fish to these impacts has still not been assessed. Thus, in order to determine the effects of aquatic degradation on the Turk-

ish fish fauna, studies should include detailed physicochemical parameters.

This research is one of the earliest contributions to the development of a fish-based index for Turkey and it will need to be improved. More detailed research is needed to develop a synthesis and to understand WFD implementation for Turkey.

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Assessing Inland Fisheries: What Can Be Learned from Australia's Murray–Darling Basin?

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Abstract.—The collection and use of data to manage the freshwater fisheries of Australia's Murray–Darling basin (MDB) has a poor history of success. While there was limited assessment data for early subsistence and commercial fisheries, even after more robust data became available during the 1950s its quality varied across jurisdictions and was often poorly collated, assessments were not completed, and the data were underutilized by management. The fishery for Murray Cod *Maccullochella peelii* is given as an example, where the fishery declined to the point of closure and then the decline continued to the extent that Murray Cod was listed as a threatened species and all harvest now only occurs through the recreational fishery. Lessons from such poor population assessments have not been fully learned, however, as there remains a paucity of harvest data for this recreational fishery. Without a proper assessment, a true economic valuation of this fishery has not been made. As the MDB is Australia's food bowl, there are competing demands for water use by agriculture, and without a proper assessment of the worth of the fishery, it is difficult for Murray Cod to be truly considered in either economic or sociopolitical discussions. The poor state of MDB rivers and their fish populations (including Murray Cod) has, however, resulted in political pressure for the development of the sustainable rivers audit, a common assessment method for riverine environmental condition monitoring. This audit undertakes standardized sampling for fish and a range of other variables at a number of fixed and randomly selected sites on a 3-year rotating basis. While the sustainable rivers audit has provided a range of data indicating that the condition of rivers is generally very poor, these data have yet to be fully utilized to determine the potential state of the fisheries (such as Murray Cod) or to set targets for rehabilitation, such as for environmental flows. While, to date, data analyses have been somewhat restricted by fiscal constraints, more comprehensive use of data, together with full fishery valuations, should be seen as the way forward for improved management.

Introduction

Adequate assessments of data are essential for science-based fisheries management to inform management objectives; to maximize outputs, cost-effectiveness, and the longevity and sustainability of the fishery; and to reduce the risk of stock collapse. Without adequate assessments, the true value (total, not just economic value) of some fisheries may be severely underestimated or, indeed, not recognized at all (FAO and World Fish Center 2008; Kang et al. 2009). This may compromise the future prospects for fishery stocks, especially when decisions are being made about resource trade-offs that may affect them, such as water extraction for irrigation or hydopower (Allan et al. 2005). The different and disparate nature of inland fish and fisheries pose many difficulties for their assessment, with the collection of data

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recognized as particularly difficult for small-scale fisheries (Andrew et al. 2007). Such assessments are also often exacerbated by a lack of fiscal resources, particularly in rural areas and poorer nations (FAO and World Fish Center 2008). Proper assessments of inland fisheries, however, are also not always undertaken in developed nations, where resources are more plentiful, and the economic value of some commercial and recreational fisheries are also not always being fully accounted for (Cooke and Cowx 2006).

This paper provides a case study where the inadequate collection, analysis, and application of fishery assessment data to properly manage the commercial Murray Cod *Maccullochella peelii* fishery in the Murray–Darling basin (MDB), southeastern Australia, ultimately led to its closure. It suggests a way forward to manage the recreational fishery for this species into the future and also provides the example of a new assessment method for riverine environmental condition monitoring, the sustainable rivers audit, which may have applicability to other river systems.

Background

Australia is the driest inhabited continent (area 7.6 million km^2), with Aboriginal occupation dating back 60,000 years and European settlement occurring only 240 years ago. With a population of 23 million, Australia is highly urbanized, mostly settled along the eastern coast (Figure 1); it is governed by a national and eight state and territory jurisdictions. It is a developed nation with a relatively high gross domestic product (2013: per capita Aus$67,100; http://dfat.gov.au/about-australia/Pages/about-australia.aspx). The MDB (Figure 1) occupies about one-seventh of the continent (more than 1 million km^2) and was settled post-1830s. It contains 2 million people and has six partner jurisdictional gov-

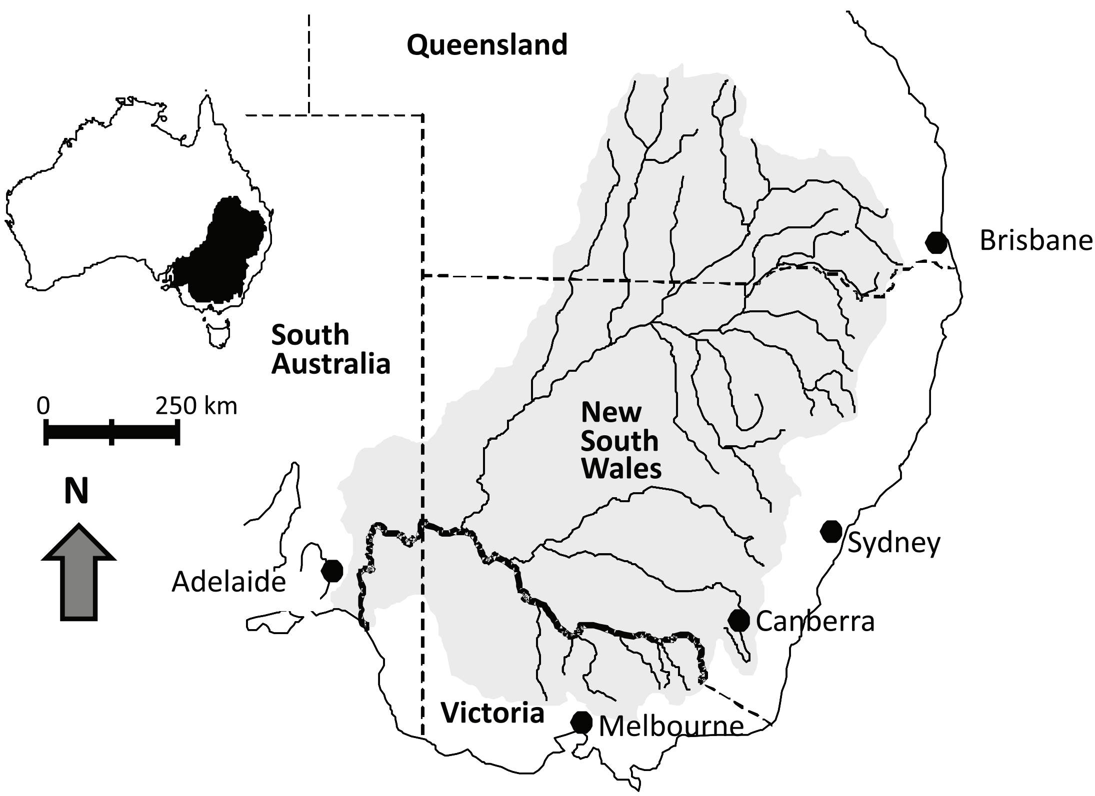

Figure 1.—Map of the Murray–Darling basin in southeastern Australia.

ernments. Agriculture occupies 84% of MDB, contributes 39% of the nation's agricultural production with a value of approximately \$15 × 10^6 per annum (2005–2006; ABS 2012) and accounts for 50% of the nation's irrigated agricultural water use (2007–2008; Koehn 2015). The concentration of agricultural development, most of which occurred post World War II (Figure 2) has resulted in significant ecological pressure on aquatic systems, with high levels of flow regulation, water abstraction, and floodplain and riparian modification (Murray–Darling Basin Commission 2004). This has led to concerns about overallocation of water (Lester et al. 2011), which were highlighted by the Millennium Drought (1997–2010; Murphy and Timbal 2008), which greatly impacted both irrigated agricultural production and environmental assets (Kingsford et al. 2011).

A range of reforms, including the Basin Plan have been initiated to address the need for complimentary management of water across the competing demands of irrigation and the environment with the aim to allocate increased amounts of water to improve riverine environments (Murray–Darling Basin Authority 2011). The Basin Plan has proven to be one of the most controversial reforms of natural resource management in Australia's history, generating high levels of political debate and public protest from regional irrigators as it aimed to reduce the consumptive use of water by up to 4,000 GL/year at an estimated cost of \$3.1 × 10^6 (Koehn 2015).

The MDB has a limited native fish fauna of only 44 naturally occurring species (Lintermans 2007), which are impacted by a range of threats (Cadwallader 1978; Murray–Darling Basin Commission 2004). Native fish have suffered serious declines, and overall, populations are estimated to be now at about 10% of their pre-European settlement levels, with many localized extinctions, many species of conservation concern, declines in flagship species, and concerns about declines in recreational angling success (Koehn and Lintermans 2012). Definitive assessments of these populations was difficult, however, as there are few con-

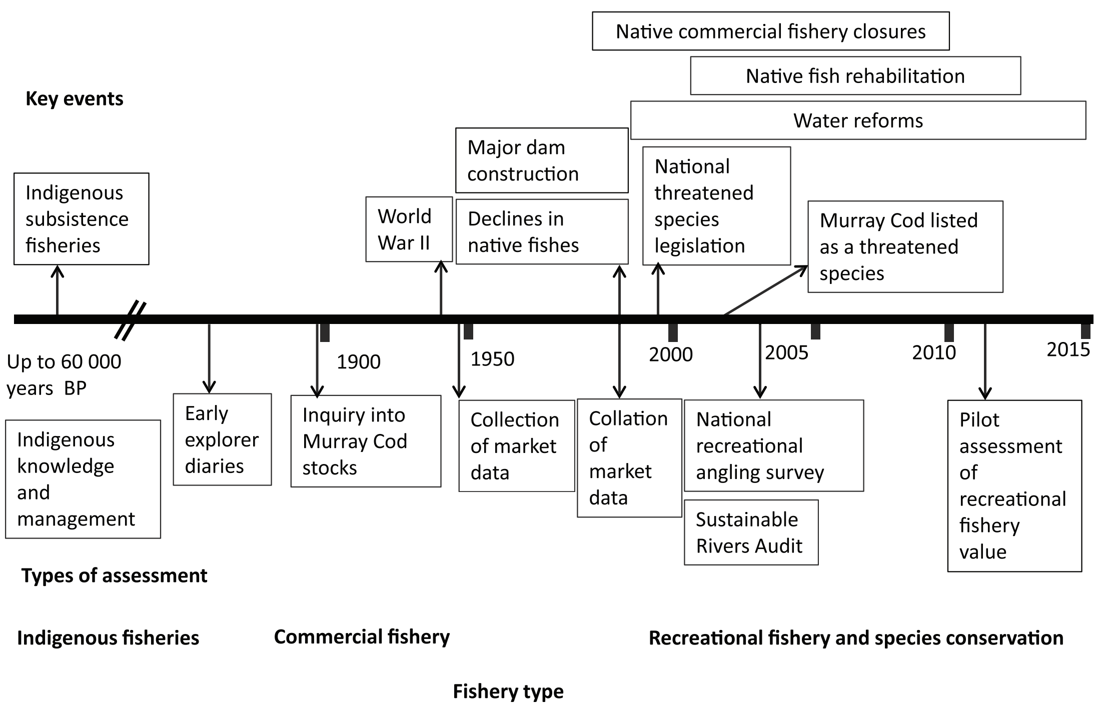

Figure 2.—A timeline for key events, assessments, and management of native fisheries in the Murray–Darling basin.

sistent, quantitative data available on species' population status (e.g., Cadwallader 1977; Cadwallader and Gooley 1984). Most assessment data comes from commercial fishery market documents, which are only available for a few species (Kailola et al. 1993) and have a lack of consistency across species and jurisdictions, which has greatly hampered the analyses of population trends and status (e.g., Forsyth et al. 2013; Ye et al. 2014).

Native fishes of the MDB were harvested only for subsistence by native Aboriginal tribes (Dargin 1976) until after the mid-1800s when more wide-scale commercial fisheries were introduced (Figure 2). These commercial fisheries expanded rapidly, concentrating on a few, larger species. One of the most popular species was the large Murray Cod (see Rowland 1989, 2005; Lintermans 2007), which is distributed throughout most of the MDB. Initially, there was limited market data for this fishery, but by the early 1900s there were already concerns about potentially unsustainable catch rates (Dakin and Kesteven 1938; Figure 2). Even after considerable market catch data were available (1950s), their quality varied across jurisdictions and they were often poorly collated and therefore had limited use by management. Commercial fishery data from the state of New South Wales showed a rapid decline in Murray Cod after 1960 (Figure 3; Reid et al. 1997), and this fishery was closed in September 2001. Other jurisdictional fisheries for Murray Cod were also closed, with all harvest now only undertaken through the recreational fishery. The decline of Murray Cod was such that it was listed nationally as a threatened species (International Union for Conservation of Nature vulnerable category) in 2003 (Department of the Environment and Heritage). Even today, for this threatened and important species, limited utilization of data for management continues, with a paucity of assessment data for the recreational fishery harvest. In a recent attempt at stock status assessment, Murray Cod was deemed to have undefined stock status in all jurisdictions due to a lack of data (Ye et al. 2014). A true assessment of harvest by the recreational fishery has not been quantified, and an economic valuation of this fishery has also not yet been made (Ernst and Young 2011).

The Sustainable Rivers Audit

The decline of the Murray Cod fishery, together with other environmental factors, highlighted the poor state of MDB rivers and provided political pressure for the development of the sustainable rivers audit (SRA). The SRA provides a dedicated assessment method for environ-

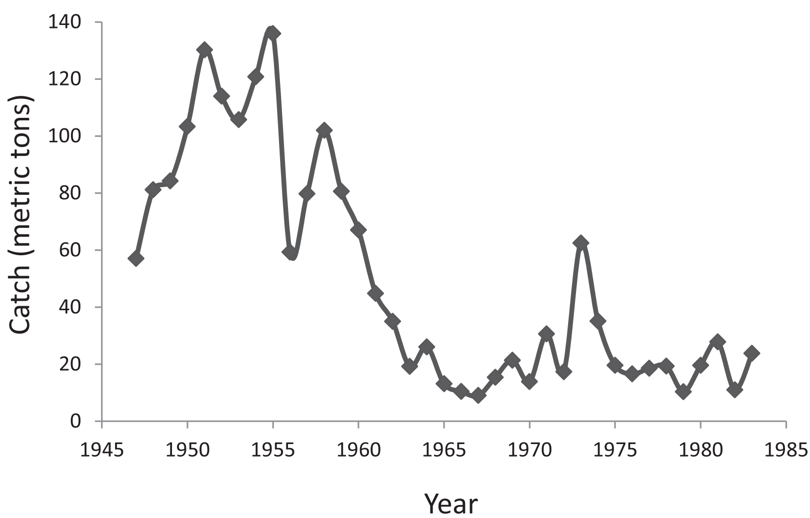

Figure 3.—Annual catches of Murray Cod from the New South Wales inland commercial fishery between 1947 and 1984. (Data from New South Wales Fisheries; Reid et al. 1997).

mental condition monitoring. Previously, any management assessments were made from disparate, ad hoc data collections. This audit undertakes standardized sampling for fish and the collection of a range of other variables on a rotating basis (every 3 years; Davies et al. 2012). This fish community sampling includes all species and is undertaken in rivers (not lakes or wetlands), using standard methods, by all jurisdictions across the MDB. This fish community approach, together with the collection of other variables, has differences to many traditional stock assessments. For example, historical records were used to develop a list of species that would have been expected to occur at each sampling site. There were some challenges to transferring from an ad hoc to a standardized approach, with considerable resources allocated to consultative workshops, method development, and training. Sampling sites are randomly selected in montane, upland, slopes, and lowland zones, with the data being compiled to produce a series of indices and end of valley scores. Fish sampling methods include electrofishing (boat; 12 × 90 s on-time or backpack; 8 × 150 s on-time), and bait traps (unbaited, unlighted; 90–150 min)

These measures are amalgamated into a series of fish metrics: expectedness (species observed: species expected from historical records); nativeness (natives: aliens), species' abundance and biomass, recruitment (index of juvenile fish indicating recruitment), and an overall fish index. Data on supplementary variables, such as water temperature, conductivity, turbidity, depth, width, and woody habitat, are also collected (see Davies et al. 2012).

Results from the 2005–2007 sampling confirmed the concern about the health of rivers in the MDB with 19 of 23 river valleys rated in "poor" to "extremely poor" ecological condition (Davies et al. 2010; Figure 4). These data were collated from sampling undertaken at 487 sites (23 valleys), catching 60,600 fish (4 metric tons). Expected species were only caught at 41% of sites. Similar data were obtained from the following cycle of sampling (2008–2010; Davies et al. 2012). Such sampling, however, is very intensive and had an annual cost of about \$1.2 × 106. While the SRA has provided a range of data indicating that river conditions, in general are very poor, it has yet to be fully utilized to determine the potential state of the fisheries such as Murray Cod.

Discussion

Historically, there has been a lack of data collection, collation, analysis, and use to inform fisheries management in the MDB. This has contributed to the decline in populations of Murray Cod, the major commercial and angling

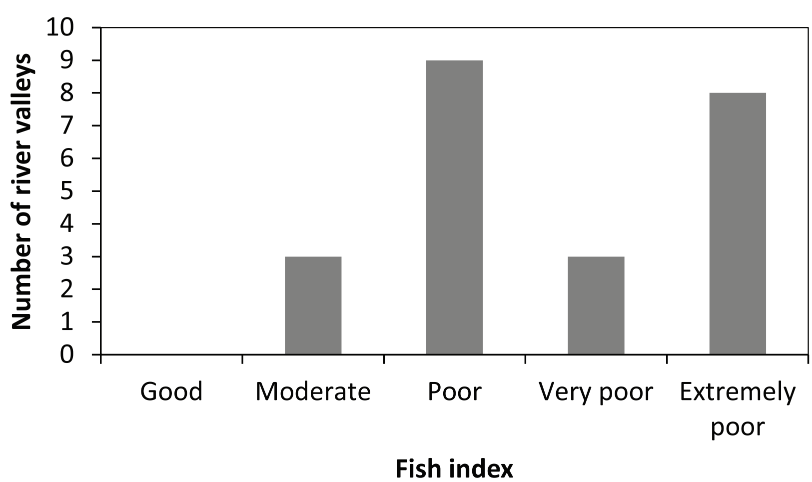

Figure 4.—Sustainable Rivers Audit fish index scores for the number of river valleys in the Murray–Darling basin (2005–2007). (From Davies et al. 2010).

species, to the point where it now has threatened species status and a national recovery plan has been prepared (National Murray Cod Recovery Team 2010). The lack of a stock status (Ye et al. 2014); recreational fishery harvest assessments; especially on a catchment or regional basis (Henry and Lyle 2003); and quantitative economic valuations of the fishery (Ernst and Young 2011) mean that Murray Cod has largely been ignored in the water-reform debates for the MDB (Koehn 2015). In separate analyses, an initial assessment of the economic contribution of recreational angling to the MDB suggested likely estimates of $1.35 × 10^9 direct expenditure; $357 × 10^6 added expenditure; a $403 × 10^6 contribution to gross domestic product; and a contribution of 10,950 jobs (Ernst and Young 2011). In addition to these economic evaluations, the public clearly realizes that other social and cultural values of fishes (Ginns 2012) should be recognized as a way to illustrate benefits of the Basin Plan (Koehn 2015).

Historically, data have only been available for a few, large MDB fish species, and consistency in collection, collation, and availability has been variable across jurisdictions. The instigation of a more comprehensive assessment of fishes has occurred only after the Murray Cod fishery had declined. The Sustainable Rivers Audit provides a comprehensive data set for the assessment of river condition that comprises a set of agreed measures, including fish populations, that has greater scientific rigor and acceptability among jurisdictions and their management agencies. While this type of assessment may differ from true fisheries stock assessments, it does provide widespread, consistent data that can be further mined and added to. For example, data trends over time (especially long term) will provide baselines from which the recovery of species (Koehn et al. 2013) or rehabilitation of the native fish community (Koehn and Lintermans 2012) can be measured and rehabilitation targets set. This is especially important for the provision of environmental flows (Koehn et al. 2014; Koehn 2015). Additional information such as catch detection rates (Lyon et al. 2014) and recreational harvest may be incorporated with SRA data to help more accurately reflect true population levels. Such assessments can also inform population models that allow management to be more predictive in its outlook by testing the potential outcomes for different management options (Koehn and Todd 2012).

Despite not having many of the constraints of small-scale, subsistence fisheries in poor, developing countries, the example of the Murray Cod fishery of the MDB also highlights that lack of proper fisheries assessment data and their use can also occur in developed nations, to the great detriment of the fish and fishery. While the Sustainable Rivers Audit has provided a comprehensive environmental monitoring program, collecting a range of data on river conditions, these data have yet to be fully utilized to determine the potential state of the fisheries or to set targets for their rehabilitation (such as for environmental flows; Koehn et al. 2014; Koehn 2015). While, to date, data analyses has been somewhat restricted by fiscal constraints, further use of the data by a range of agencies, together with fisheries valuations, should be seen as the way forward should be utilized to better manage the fisheries.

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The Underappreciated Livelihood Contributions of Inland Fisheries and the Societal Consequences of Their Neglect

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Abstract.—Inland fisheries provide important contributions to human well-being, but these contributions are often overlooked or undervalued by decision makers. Consequently, inland fisheries are not adequately considered in either global fisheries sustainability initiatives—which are generally marine-focused—or in the use of freshwater resource planning in an era of water crisis. Here we synthesize the state of knowledge of the contribution of inland freshwater fisheries to human well-being. To date, there has been no coordinated global valuation of the ecosystem service contributions of inland fisheries, and it is thus only possible to highlight the range of services they provide from isolated case studies. Throughout these studies, human nutrition emerges as a key value, with freshwater fish providing essential nutrients in countries such as Cambodia and Bangladesh, which are endowed with productive freshwater fisheries. Inland fisheries also provide livelihoods, income, economic autonomy, dietary diversity, cultural identity, and social structure to tens of millions of people around the world. The diversity of fishing methods, conservation strategies, and traditional ways of managing fisheries enriches the human experience and represents a source of cultural and technical knowledge and human institutional ingenuity. In this paper, we review what is known about approaches for assigning values to freshwater fisheries and identify methods to better assess and communicate those values to decision makers and the public in order to increase representation of inland fisheries in natural resource decision-making processes. Most importantly, we focus on the contributions of inland fisheries to food security, nutrition, community cohesion, and improved livelihoods. This paper also explores approaches that consider the knowledge and perspective of fishers, fish workers, other aquatic resource users, and their communities to augment and improve the knowledge and perspective of scientists and resource managers in better managing freshwater fisheries resources. We also stress the importance of ensuring that assessments explicitly consider gender relations and roles in inland fisheries and fishing-dependent societies. Better recognition and valuation of the economic, nutrition, and social benefits that inland fisheries provide to human communities is an essential step toward better incorporating inland fisheries into future water and food security policies.

Introduction

The vast majority of global inland fisheries catch is used for direct human consumption (Welcomme et al. 2010). These important and productive food resources, however, are often negatively impacted because decisions about the allocation and management of inland waters often either ignore or do not include an accurate assessment of the economic, societal, and cultural values that inland fisheries contribute to society (Bartley et al 2016, this volume). This exclusion from decision-making processes partially occurs because information about the valuable contributions of inland fisheries to economic, social, and individual well-being is not well documented or effectively communicated, especially to policymakers. Although a few case studies exist (Béné and Neiland 2003; Baran et al. 2007; Navy and Bhattarai 2009), no global assessment of the value of inland fisheries has yet been conducted. In instances where there is some estimate of the monetary value of these fisheries (usually in terms of fishing income and profits or license and tax revenues), economic assessments have often ignored the important contribution of freshwater resources to nutrition, health, livelihoods, leisure, individual and societal well-being, as well as the values associated with religious and cultural uses of freshwater resources (UNEP 2010; Welcomme et al. 2010). This incomplete portrayal of inland fisheries contributions lessens their value and importance to decision makers, especially those more distant from the local communities where the fish are captured. The absence of inland fisheries from the decision-making process is also partially due to the inaccuracies and uncertainties surrounding current inland fisheries assessment and reporting (Cooke et al. 2016; Lymer et al. 2016a; both this volume).

In assessing the overall values of inland fisheries, it is essential to focus on both the ecosystem services (e.g., habitat, freshwater, fish, and biodiversity) and the flows to the social and economic sectors (e.g., fishers, processors, and others involved in inland fisheries) that are involved in inland fisheries. To ensure that each of these components are given proper consideration when assessing the value of inland fisheries to human societies, a conceptual framework capable of articulating the various services provided by inland fisheries and methods of how to best to assess these contributions is required. Smith et al. (2013) suggests a framework for linking general economic, social, and ecosystem goods and services to human well-being. The framework has nine domains of well-being: health, social cohesion, education, safety and security, living standards, spiritual and cultural fulfillment, life satisfaction and happiness, leisure time, and connection to nature. We have adapted this framework into a fisheries context to illustrate its utility in linking the economic, social, and ecosystem goods and services provided by inland fish and fisheries to human well-being (Lynch et al. 2016b; Figure 1).

Each of the nine domains of well-being is important to gain a full understanding of the role and importance of inland fisheries to economic, societal, and environmental well-being, which combine to describe overall human and societal well-being. These nine domains relate to inland fish in many ways:

- In the context of inland fisheries, the domain of health focuses on outcomes of personal well-being, life expectancy and mortality, and physical and mental health conditions from reliance on inland fisheries for nutrition, including micronutrients during the first months of life from conception to 24 months.
- The domain of social cohesion focuses on outcomes such as identity, family demographics, and social norms, stemming from social network ties among individuals and within communities, enhancing the quality of life for those dependent upon inland fisheries.
- The domain of education focuses on outcomes derived from formal and informal education and skills transfer, which enhance basic capabilities that lead to the expansion of other capabilities necessary for well-being development. In the context of inland fisheries, education capabilities are an antecedent to the ability to adjust effectively to market or technology changes.
- The domain of safety and security focuses on outcomes related to overall freedom from harm, promoting personal physical security, national security, and financial security. In our context, reliance on inland fisheries can promote financial security, especially for women or children, by providing for enhanced livelihoods and income.
- While the domain of living standards is largely economic in nature, this domain focuses on outcomes related to income, living conditions, home ownership, and household assets accessible as a result of inland fisheries activities.
- Cultural values of inland fish or symbolism related to fish may promote the domain

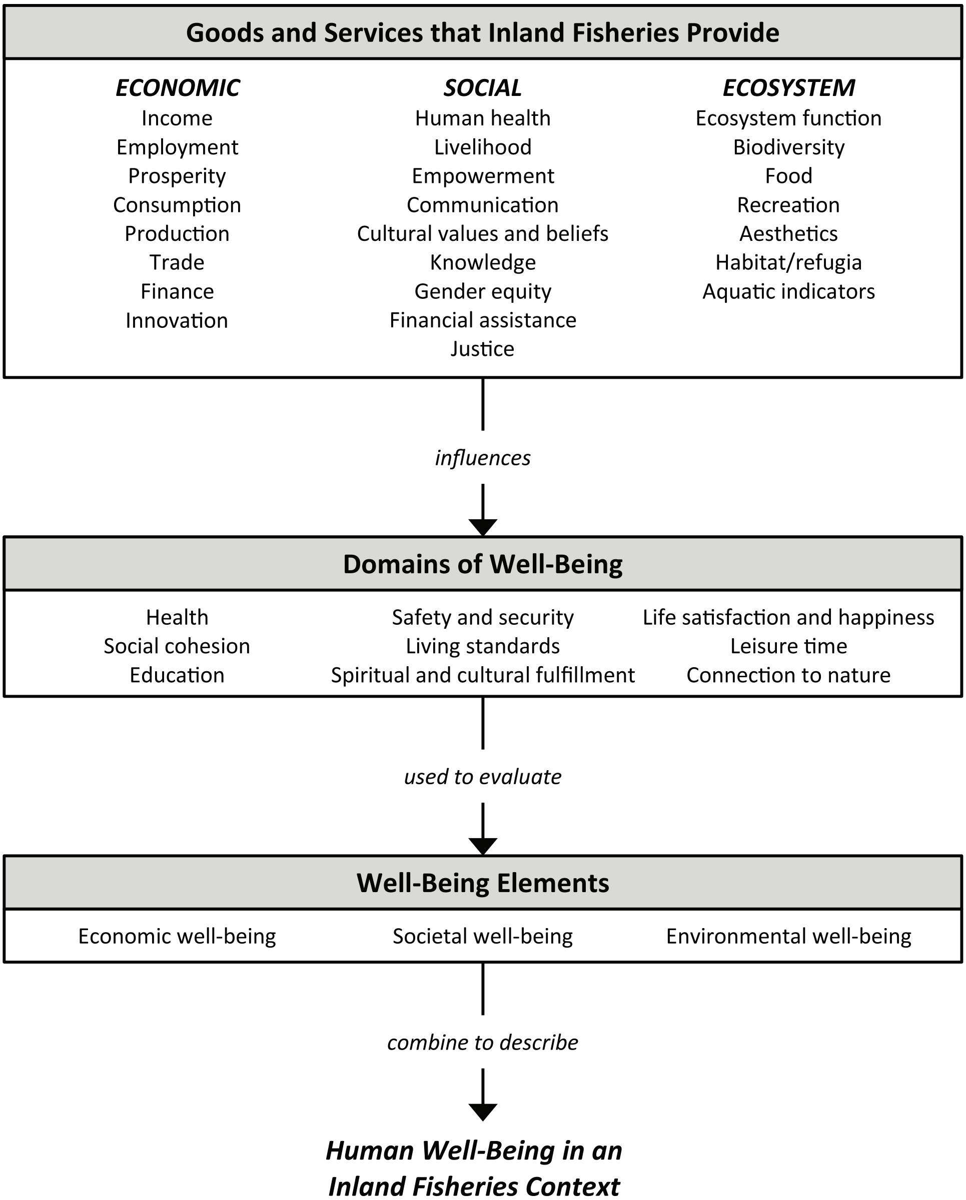

Figure 1.—Elements of a framework that link economic, social, and ecosystem goods and services provided by inland fish and fisheries to human well-being. (Adapted from Smith et al. 2013).

of spiritual and cultural fulfillment, which focuses on outcomes related to interconnections between one's self and others and the environment as a result of access to religious activities, cultural interests and identity, and a connection to nature.

- The domain of life satisfaction and happiness focuses on outcomes related to self-reported happiness and whole-life satisfaction. Life satisfaction and happiness with inland fisheries in the developed world may occur at higher rates than in the developed world, in part because life satisfaction tends to plateau in the wealthier, developed world. Perhaps more appropriate to the developed world than the developing world, inland fisheries may be a focus of pleasurable activities that people are able to engage in outside of their work or other responsibilities (e.g., fishing, fish ing clubs), resulting in outcomes in the domain of leisure time.

- The domain of connection to nature focuses on outcomes related to biophilia—an emotional attachment of human beings to other living organisms (Wilson 1984; Smith et al. 2013). Measures of biophilia can describe the connection people have with inland fisheries or their ecosystem services. In the developing world, the relationship among humans, inland fisheries, and their ecosystem services may be curvilinear. People in the developing world likely have strong biophil ia; as their livelihood dependence on in land fisheries wanes so too does biophilia, until individuals rely again on inland fisheries for other reasons such as leisure time.

While the human well-being framework depicted in Figure 1 may be appropriate for a global context, it is essential to clarify which domains are more appropriate for inland fisheries in a developing context than in a developed context, and vice versa. A holistic framework, one that incorporates gender roles, power dynamics, and political ecology, will be more effective for valuing, and in the valuation of, inland fisheries to society. Further, when methods and metrics are solidified and implemented to value the social, economic, and ecosystem goods and services provided by inland fisheries, their contributions become even more prominent in society. However, some challenges exist in the determination of the value of inland fisheries, as discussed in the next section.

Challenges associated with valuing inland fisheries

It is difficult to accurately assign a monetary value to inland fisheries because they are complex, and geographically diffuse and occur largely outside formalized markets (Welcomme et al. 2010). Harvest and use (e.g., consumption, recreation, and livelihood) statistics, particularly in the developing world, are often unavailable or inaccurate (Welcomme 2011). Many areas lack the infrastructure, labor force, or capital needed to generate harvest estimates and check the accuracy of existing estimates (Welcomme 2011). Additionally, because many inland fisheries are so diffuse, many agencies opt to collect data only on larger-scale commercial fisheries and report little or no data on others (e.g., subsistence fisheries, recreational fisheries; FAO 2003; Kang et al. 2009). The livelihood and food security benefits provided by inland fisheries are also difficult to measure since many inland fisheries are subsistence based and thus occur outside of formal markets, rendering the value of most inland fish transactions invisible to normal channels of data collection on economics (Bartley et al. 2015). Some methods, such as indirect-use valuation and the travel-cost method, have been applied to inland fisheries in the Mekong basin (Baran et al. 2007) and the Copper River in Alaska (Henderson et al. 1999). In general, however, very few valuation studies have been done of subsistence inland fisheries.

Compounding the difficulties of valuing inland fisheries are the challenges associated with valuing freshwater ecosystems in general and the impact that external drivers (e.g., changes in land use, climate change) have on inland fisheries (Brummett et al. 2013). The complex interactions of climate, water, and land use challenge creation of projections of the impacts that climate change will have on inland fish and those who rely on them (Lynch et al. 2015). Illegal and destructive fishing methods, coupled with inadequate enforcement of fishing regulations, complicate assessment of inland fisheries and further challenge the assessment of actual catches (Allan et al. 2005). Improved low-cost approaches for estimating fish harvests and methods to trace flows of inland fish through ecological and human systems would help to reveal the largely invisible values of inland fisheries.

The contribution of inland fisheries to health and food security

Food and nutrition security is one of the most important ecosystem goods and services provided by inland fisheries, the majority of which are used for direct human consumption (Youn et al. 2014). It is generally accepted that direct consumption of inland fish plays an important role in the diets of many population groups, particularly in the developing world (Roos 2016; Funge-Smith 2016; Lymer et al. 2016b; all this volume). Exploring and supporting this generalization, however, is very difficult due to lack of reliable data on direct human consumption, indirect human consumption (e.g., use of inland fish in animal feeds), and nutrients present in inland fish (Welcomme 2011; FAO 2014; Bartley et al. 2015).

Freshwater ecosystems and the inland fisheries they support are diverse and can have high productivity of fish and other aquatic species that feature in people's diets or can be sold to support food and livelihood security (Dudgeon 2000; Kang et al. 2009). This diversity of inland aquatic organisms, especially the smaller fish species, is an important nutrition source for human communities. All fish species are a rich source of animal protein (Beveridge et al. 2013). Additionally, small fish, which are eaten whole (bones, organs, and head), contribute essential minerals and vitamins, such as calcium, phosphorus, zinc, iron, and vitamin A, to the human diet (Roos et al. 2003). Due to their size, it is often difficult to consume large fish whole, and thus, large fish do not provide these same nutrients. The micronutrients provided by freshwater fish are often inaccessible to local communities in other forms, either due to price or unavailability of substitutable food sources that contain these nutrients.

Freshwater fish also have been reported to enhance the bioavailability of micronutrients from the other foods consumed during the same meal since nutrients in the fish enhance bioabsorption of nutrients present in the food (Tontisirin et al. 2002). Micronutrient contributions from inland fish are especially vital to economically disadvantaged people as they tend to suffer disproportionately from micronutrient deficiencies, which have debilitating effects on human nutrition, health, and survival, due to decreased access to nutrient-rich foods (Fischer et al. 1999; Combs and Hassan 2005; Roos et al. 2007). Traditional knowledge of local communities on the nutritional and health attributes of many inland-capture fish species also points toward the great value given by these communities to inland fish and people's desire to ensure the continued use of these fish as part of their families' diets and livelihoods (Roos et al. 2003).

Even though exact data regarding harvest, transactions, and consumption of fish from inland fisheries are scarce, it is generally accepted that inland fish contribute significantly to the consumption of animal-source foods in rural populations in Africa and Asia, especially during the peak fish-capture season (Belton and Thilsted 2014). Fish consumption varies widely across countries, seasons, and population groups, and there are very little data for household fish use (e.g., different forms of consumption, bartering) beyond national economic surveys. National data may mask the critical contribution of inland fish to the food security of a particular region or population. Equally important, there is limited understanding of intra-household food dynamics regarding the quantity and parts of the fish that different members of the household consume. For instance, gender may be an important aspect influencing consumption of inland fish within a household because there is evidence from many countries that females consume smaller portions of fish and other animal-source foods compared to males (Béné and Heck 2005; Kawarazuka and Béné 2010). As a result women, compared to men, often do not receive the same nutrient and food benefits from inland fish, which can exacerbate nutrient deficiencies in women, particularly pregnant or lactating women. In some cases, these are real differences due to cultural factors, where males eat first and have larger portions; elsewhere, this may be due to reporting bias in the survey methodology (Gittelsohn 1991; Geheb et al. 2008). Real differences in the amount of fish consumed would affect household food security and the nutrients each household member receives from inland fish.

Another important aspect regarding consumption of fish is people's access to markets or other fish sources. Studies in Bangladesh show that in communities close to water bodies with productive capture fisheries, only one-third to one-fourth of fish consumed was self-caught and the majority of fish consumed was bought from nearby markets (Hels et al. 2003), suggesting that local fisheries are an important source for community food security. Again, gender and social roles are an important aspect to consider as the power to purchase fish, and thus access its nutritional benefits, may not be realized equally among different socioeconomic groups and within households (Béné and Merten 2008; Belton and Thilsted 2014).

In many areas, women and children take part in capturing inland fish, and these fish are generally used for household consumption (Bose et al. 2009). Infants and young children can also significantly benefit from consumption of inland fish (Roos 2016). There is growing recognition of the positive impact fish, via nutrients found in fish, can have on growth, development and cognition in infants and young children (Daniels et al. 2004). The role of essential fats, especially the importance of omega-3 fatty acids for brain development, is well known (Horrocks and Yeo 1999; He et al. 2004), and some freshwater fish (e.g., Rainbow Trout Oncorhynchus mykiss and Common Carp Cyprinus carpio; Guler et al. 2008; Gogus and Smith 2010) have high amounts of these nutrients. Studies on developing fish-based products using small indigenous species with high micronutrient content have been conducted in Bangladesh, Cambodia, and Kenya among pregnant and lactating women and young children up to 24 months of age (Andersen et al. 2003; Longley et al. 2014). These studies illustrate the important benefits that the nutrients in inland fish provide to these vulnerable groups. The first 24 months are considered the first 1,000 d of life, a window of opportunity for ensuring optimal child growth and development that can lead to long-term optimal nutrition, health, and development for the individual child and better national and global development for society (Roos 2016). However, the nutrient content of many inland fish species, even frequently consumed fish species, is not well known (Bogard et al. 2015) as nutritional profiles have tended to focus on larger fish, typically from aquaculture, which may have different nutrient profiles than wild fish and fish on lower levels of the food web. Determining the nutrient content of fish species and thus their contribution to nutrition is an important first step to understanding, analyzing, and promoting the present and future potential of inland fisheries to improve global food and nutrition security (Roos et al. 2007).

Valuing the contribution of inland fish to human society

Freshwater ecosystems support a diversity of livelihoods and cultural values. For instance, freshwater recreational fisheries in the United States are known to support more than 500,000 jobs generating more than US$30 × 109 in retail sales and contributing more than $9 × 109 in tax revenues (Southwick Associates 2012). Inland fisheries also support commercial fishing industries, such as in the Laurentian Great Lakes (Cooke and Murchie 2015) and the African Great Lakes (Okeyo 2014), and remain important in some European countries, despite shifts in dietary preferences and multiple pressures on freshwater use and allocation. Commercial fishing in France (Boisneau et al. 2016, this volume) was estimated to produce 1,186 metric tons valued at €10,470,000 (EU 2011).

Livelihoods reliant on inland fisheries, whether recreational or commercial, are also vulnerable to social, biological, environmental, and economic changes that can reduce access to inland fisheries or decrease the productivity and value of the fishery (Cowx 2015). Because inland fisheries provide different livelihood benefits to different people (e.g., fisheries are not always a livelihood of last resort), policies regarding inland fisheries need to account for the different livelihood values that fishers obtain from inland fisheries (Smith et al. 2005). It is not sufficient to assume that fishers are a homogenous group and that this allows the blanket application of policies for management, development, or conservation.

Inland fisheries and their aquatic environment have essential cultural roles for many rural (Fregene 2016; Ibengwe and Sobo 2016; both this volume) and indigenous cultures (Bartley et al. 2016) that largely rely on traditional freshwater resources (Clarke Historical Library, no date). In the Northwest of the United States, more than 40 tribes have very close cultural and livelihood ties to aquatic resources (Ruby and Brown 1986). In fact, they refer to themselves as the "people of the salmon," and they honor the salmon as their first indigenous food gifted to them by the Creator (Columbia River Inter-Tribal Fish Commission, no date). The rights of the Pacific Northwest tribes to fish for salmon are closely guarded by the tribes. The ongoing struggle by the native people of North America to have their tribal fishing rights recognized has also occurred in the tribal people of South America, specifically the Amazonian region (Barra 2016, this volume). It has been widely reported that the rights and needs of the largely uncontacted tribes of the Amazon River basin are being ignored during development and transformation of the river system by not only corporations, but also by the governments that are supposed to protect them (Shukman 2012). The loss of access to fishing and fishery resources threatens not only food security, but also cultural traditions and historical livelihoods sources; it may result in the long-term loss of cultural identity and reduce the prospects of maintaining a traditional community and lifestyle into the future, particularly when compounded by other environmental threats such as large-scale mining (Malm 1990), oil drilling, and government-driven deforestation (Shukman 2012). Malm (1990) has shown that runoff from illegal, as well as legal, mining and drilling operations releases mercury-based compounds into the Amazon watershed and river system, which results in bioaccumulation within the freshwater fishery resources upon which these tribal peoples depend (Malm 1990). In summary, without representation on the local and global stages, these groups are subjected to health risks and shorter life spans due to reduced access to freshwater fishery resources (McClain and Naiman 2008; UNPFII 2010).

Recommendations to Effectively Communicate the Social and Economic Value of Inland Fisheries

Improving our ability to assess and communicate accurately and effectively the social and economic value of inland fisheries is critical to ensure both ecosystem and human well-being. During the 2015 global conference on inland fisheries, a group of panel experts explicitly focused on this ongoing challenge. This panel agreed that an approach, on local and international levels, that considers the social and cultural aspects of inland fisheries is needed so that valuation of inland fisheries effectively includes the social value of inland fisheries in addition to their economic values. It is also important to understand that fishers are not a homogenous group and thus may vary in regards to the value they place on various aspects of inland fisheries. Indeed, while much research and management effort has been expended on identifying drivers of change affecting inland fisheries productivity and sustainability (Lynch et al. 2016a, this volume), comparatively little attention has been given to understanding the lives of the driven—the people affected by change. In particular, the perspectives and lives of those with unequal social status (e.g., women, small-scale fishers) need greater incorporation into inland fisheries and natural resource governance. They also need to be included in decision-making processes, as inland fisheries are a key social and economic resource for these groups (McGoodwin 2001; FAO 2015). This panel formulated two main recommendations that are now part of the "Rome Declaration: Ten Steps to Responsible Inland Fisheries" (this volume): (1) correctly value inland aquatic ecosystems, and (2) promote the nutritional value of inland fisheries. Below, we expand on these two recommendations and provide suggestions for moving forward.

Improve systems for fish valuation—monetary and otherwise

Value methods that incorporate economic values with sociocultural values need to be used in order to estimate the contributions of inland fisheries to human health and well-being. Approaches used elsewhere in the natural resources sector and in the valuing and valuation of ecosystem services may apply to the inland fishery sector (Kontoleon and Swanson 2003; Davidson 2013). Some examples of potential economic methods that could be applied to inland fisheries include shadow pricing, replacement value, and willingness to pay (Smith 1996; Howarth and Farber 2002), which have been applied to other natural resources, such as applying shadow prices to adjust the market value of stumpage (Huhtala et al. 2003). Assessments from a public health, social, or ethnographic perspectives may focus on themes such as understanding livelihoods, assessing health and nutritional status, measuring well-being, the analysis of class and gender dynamics, understanding relations of power and accountability, the functions of governing institutions in fisheries and water-use decisions, and the value of local and indigenous knowledge systems regarding management of, and benefits from, inland fisheries (UNEP 2010).

These methods have rarely been applied to the inland fisheries context, in part because of the limited attention these systems have received to date. Using these methods in the context of inland fisheries to increase knowledge and awareness regarding the ecosystem services inland fisheries will provide and generate both monetary and nonmonetary values (e.g., cultural, human health and nutrition, and livelihood) for the appropriate assessment of the contributions of inland fisheries to human communities.

In addition to applying existing economic assessment methods to inland fisheries, frameworks that are uniquely designed to incorporate traditional ecological knowledge, sociocultural values attributed to inland fisheries, and the contributions of inland fisheries to human ecosystem health and well-being are needed. In order to do this, new approaches of measuring social value must be developed. Some current approaches (e.g., welfare valuation methods, supply chain analysis) exist, but comprehensive valuation frameworks that improve quantification of use and nonuse values (especially how to appropriately quantify the importance and value of culture and beliefs) of inland fisheries need to be developed to ensure that important hidden values are not dismissed or overlooked in favor of simplified monetary cost–benefit calculations.

Valuation methods, such as comprehensive impact assessments, should account for positive and negative spillover effects beyond the fishery (wider impacts). Assessments should incorporate both social and environmental impacts (e.g., social and economic impact assessment) and propose mitigation strategies where negative impacts are likely to occur. Additionally, frameworks that apply across contexts (e.g., geographical areas, waterbody type, and fish species) would help to standardize values assigned to inland fisheries and enable comparison of the values of different fisheries. Such frameworks would also enable freshwater ecosystems to be weighted according to their ecological and, by extension economic, benefits. The most obvious application of this is ensuring that inland fisheries are more effectively accounted for in broadscale planning of water management or rural development.

Most importantly, the promotion and adoption of approaches that include valuation of inland fisheries along the entire fisheries value chain (e.g., using participatory value chain analysis) should be supported to ensure that the real value of a fishery is captured. Doing so would facilitate inclusion of social processes that affect the value and perception of fish. This may also help explain the price dynamics of inland fisheries products, which can often seem unrelated to local contexts of supply and demand. The lack of value chain considerations often results in the somewhat limited assumption that the whole value of a fishery lies at the first point of sale, rather than acknowledging the value addition and diffusion of economic benefits and nutrition far from the source of fish. In some cases in Africa and Asia, these value chains extend across countries and even into neighboring countries.

Communicate and promote the value of inland fisheries

Improving communication of information to policymakers, freshwater users, and other stakeholders is equally important in addressing research needs and data gaps concerning the economic, health, and well-being benefits of inland fisheries. Rendering information on the value and functions of inland fisheries in both human and environmental terms in a form that is understandable to stakeholders is critical to ensuring continued access and sustainable use of inland fisheries. Promoting understanding of the real value of inland fisheries (incorporating economic, social, and ecological values) is a crucial advocacy need. All too often, the important contributions of inland fisheries are overlooked or unknown, making it easy to roll out policies and management decisions that can directly compromise the sustainability of inland fisheries and thereby impact human health, well-being, and prosperity at the local, regional, and international levels. To enhance policy change, it is important to focus on the points that resonate with policymakers, such as the economic and social values of inland fisheries and the contribution of inland fisheries to overall food security, human health, and well-being. Additionally, awareness of the benefits of inland fisheries must spread beyond those involved in inland fisheries, requiring collaboration and communication with audiences outside inland fisheries, in particular other sectors that utilize freshwater resources.

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How National Household Consumption and Expenditure Surveys Can Improve Understanding of Fish Consumption Patterns within a Country and the Role of Inland Fisheries in Food Security and Nutrition

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Abstract.—Inland fisheries are vital to the livelihoods of some rural peoples and contribute a major source of protein, especially for vulnerable populations. Moreover, inland fisheries provide a major source of food and food security throughout the Asian region but are often overlooked in national statistics and in considerations of food security. Sixty-five percent of the reported global fish catch from inland fisheries is produced by 11 countries in the Asian region. Due to the poor quality of reporting of inland fisheries, there is low confidence in the data, and this prevents effective analysis at the subnational level. Inland fish, are, therefore, all but invisible in official fish production figures.

The consumption of fish, however, can be estimated by national household surveys. These surveys are carried out on a regular basis and to a high level of statistical accuracy and can provide a wealth of information about consumption patterns and habits. These data can also play a vital role in the development of fisheries and natural resource policies that may have considerable impact on the most vulnerable segments of the population.

This paper reports some results based on a regional review of fish and fish product consumption derived from national household consumption and expenditure surveys. It also explores the implications for the use of this type of national household consumption and expenditure surveys for improving our understanding of inland fisheries and fish consumption. The paper concludes by discussing some of the weaknesses in the use of surveys and how these may be improved to provide far more effective information in support of understanding inland fisheries and its role in food security

Inland Fisheries Can Be Significant Contributors to Food Security and Nutrition in Parts of Asia

Fish harvested from inland fisheries are a significant source of food and food security throughout Asia (So-Jung et al. 2014). Based on the statistics reported to the Food and Agriculture Organization of the United Nations (FAO 2014a), of the 16 countries of the world that produce 81% of the world's inland captured fish, 9 of these countries are in Asia (Figure 1). Eleven Asian countries produce 65.5% of global fish catch from inland fisheries (Table 1), contributing 19% of total reported fish catch for these 11 countries.

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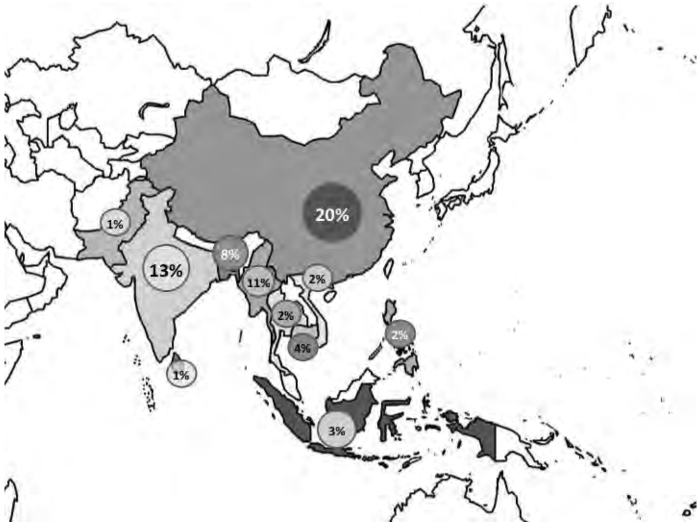

Figure 1.—Map indicating percentage contribution of Asian countries to global inland fishery catch composition. (Data source: FAO 2014a).

These inland fisheries are present throughout the large river floodplains, deltas, and rice farming areas of Asia. The large man-made irrigation tanks and reservoirs of the region also provide considerable quantities of fish in some countries. Inland fish consumption is not confined to lowland floodplains, as even in mountainous areas fish are still a prized food in many cultures in Asia (Needham and Funge-Smith 2015).

Table 1.—Reported inland fishery catches of top 11 countries in Asia (2012) as a percentage of reported global production. (Data source: FAO 2014a).

Country	Metric tons	Percent
China	2,297,839	19.8
India	1,460,456	12.6
Myanmar	1,246,460	10.7
Bangladesh	957,095	8.2
Cambodia	449,000	3.9
Indonesia	393,553	3.4
Thailand	222,500	1.9
Vietnam	203,500	1.7
Philippines	195,804	1.7
Pakistan	120,240	1.0
Sri Lanka	68,950	0.6
Rest of the world	4,014,923	34.5
Total global inland fishery production	11,630,320	

The reported inland capture fishery harvests for these 11 Asian countries are relatively significant, although these are often substantially lower than marine capture fishery production. Comparisons between inland and marine capture fisheries and aquaculture may hide the real importance of inland fisheries at the subnational level because inland fishery harvesting is often focused around specific areas where water resources are most abundant. Areas where freshwater resources are relatively abundant year round or seasonally are highly linked to increased rates of fish consumption. This local importance of inland fishing in contributing to access to fish for household consumption may be discerned to some extent by looking at the subnational details of fish consumption, derived from a household expenditure and consumption survey. For example, the fish consumption survey data of Laos indicates that the highest levels of per capita fish consumption in Laos occur in provinces along the path of the Mekong River; these areas have substantial fisheries harvest, have access to imported fish from Thailand, and also have cage and pond aquaculture production (Department of Statistics 2010). The lowest levels of fish consumption are in upland areas where fish production from rivers and streams is lower and there is relatively less aquaculture production (Figure 2.). Inland fishery capture production is, therefore, often considerably underestimated (Coates 2002) and the true importance of inland fisheries maybe diminished or undervalued in aggregated statistics at the regional or national level.

Asian Inland Fisheries Are Not Well Monitored and This Limits Appropriate Valuation

Despite their importance within some countries, the harvest from inland fisheries remains poorly reported or even overlooked in national statistics and in considerations of food security (FAO 2014b). The ability to understand and value inland fisheries remains critically linked to statistical and resource accounting systems. However, in many countries these systems are not appropriate for tracking inland fisheries. The systems for data collection and statistical analysis are typically weak in many developing countries, and this is compounded by the constraints on collecting accurate statistical data from inland fishery landings (Welcomme et al. 2010). There is generally limited investment in data collection and analysis for inland fisheries. This limited investment is partially because the cost of data collection is not eas-

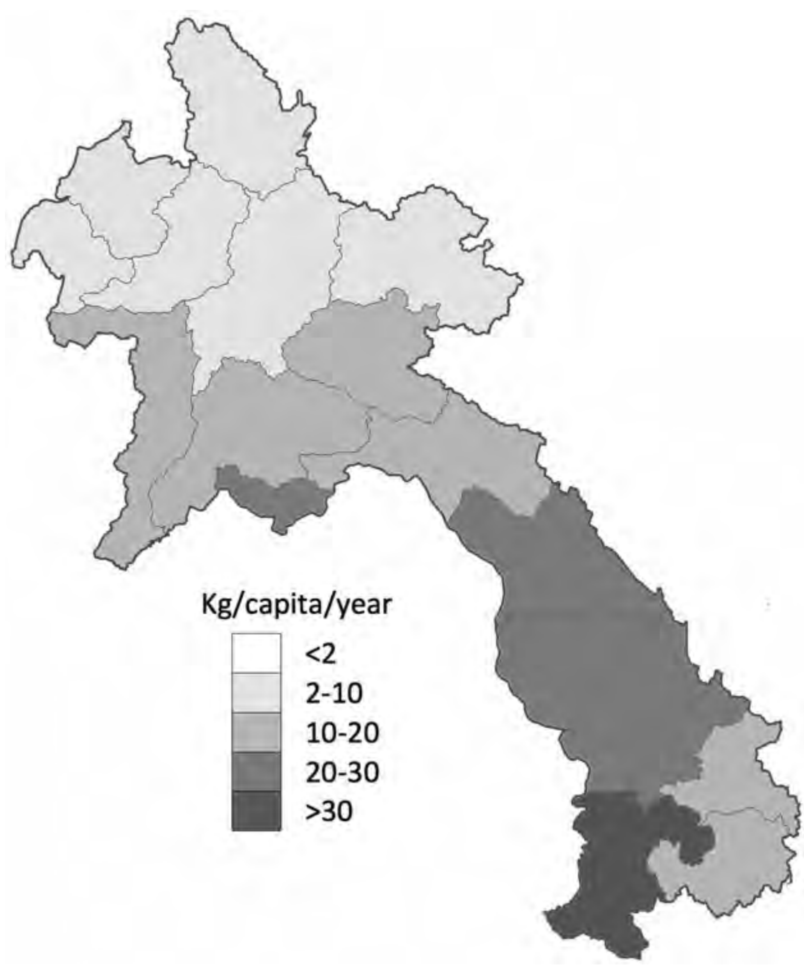

Figure 2.—Map of Laos showing within-country variations. Lightest shade of gray represents upland provinces. (Data source: Department of Statistics 2010).

ily justified by the revenue generated and fishing activity is rarely organized to a point that allows simplified data collection. Sampling schemes are rarely used for estimating inland fisheries harvest, the exception being large water bodies such as reservoirs and commercial fishing concessions. These large water bodies may be subject to greater monitoring and taxation, but this in turn drives underreporting by fishers. The inadequacy of reported statistics, coupled with the lack of subnational disaggregation for these data, severely limits meaningful discourse about what inland fisheries contribute to national and local economies, diet, livelihoods, and ecosystem services (Bartley et al. 2015).

Consumption Surveys May Improve Estimates of Inland Fishery Harvests that Are Made without a Firm Statistical Basis

In some countries, the complete absence of a statistical system means that the estimate of inland fishery harvest is essentially guesswork. There may be some indicative fisheries monitored, but inherent reporting weaknesses and the lack of representation of some key inland fisheries (e.g., rice field fisheries) means that these data cannot be used to derive an accurate national estimate. Contributing further to the inaccuracy of these data is the potential to have incremental increase applied year by year to the harvest estimates to satisfy government targets for increased harvest (author's personal observation). This can lead to very substantial accumulated errors during the course of a decade or more. For example, the inland capture fishery statistics of Myanmar indicate a massive increase (389%) during a decade (FAO 2014a). This was perhaps driven by the realization that historic reports had been greatly underestimating harvests from inland fisheries (Figure 3); however, the annual increase seems to have become institutionalized. The continuous increases year by year are too systematic and show neither natural variation nor interannual variation, as would be demonstrated in fisheries that were actually monitored. This lack of variation is considered to be a strong indication of inland fisheries harvests being estimated without validation by Coates (2002)

The use of household consumption survey data provides one approach for validating the reported inland fisheries productions. Having some form of validation would be helpful, especially in cases where very large changes in inland capture fishery statistics have been reported and where the inland fishery harvest statistics are not based on catch collection data, but on estimates. For example, the household consumption survey (2011) for Myanmar indicates that 75% of fish consumed were from inland or estuarine waters and that the majority of this was sourced from capture fisheries (Needham and Funge-Smith 2015). This gives an approximate figure of 750,000 metric tons for inland capture fisheries and indicates that the 2013 inland capture fishery statistic of 1,302,970 metric tons (FAO 2014a) may be now be overestimated by as much as 42%. This highlights the potential for using statistically robust consumption surveys as a means to validate inland capture fishery harvest.

Before being too critical of weak inland fisheries statistics, it is important to recognize that that household consumption surveys may underestimate consumption. Thus, the reported figure for inland capture fisheries may not be as overestimated as it first appears, but there is clearly substantial discrepancy that merits further investigation.

Estimations Based on Indicators such as Consumption Surveys Can Radically Change Estimates of Production

Implementing a new study or relying on alternative data to produce a robust new estimate within a country may result in a massive leap in the reported estimated production. An example of how including new data can drastically alter the reported statistic is Cambodia's inland capture fisheries production estimates. Cambodia's estimate (Figure 4) leapt 205% in 1999, followed by a second substantial increase of 57% in 2001 (FAO 2014a). The large increase

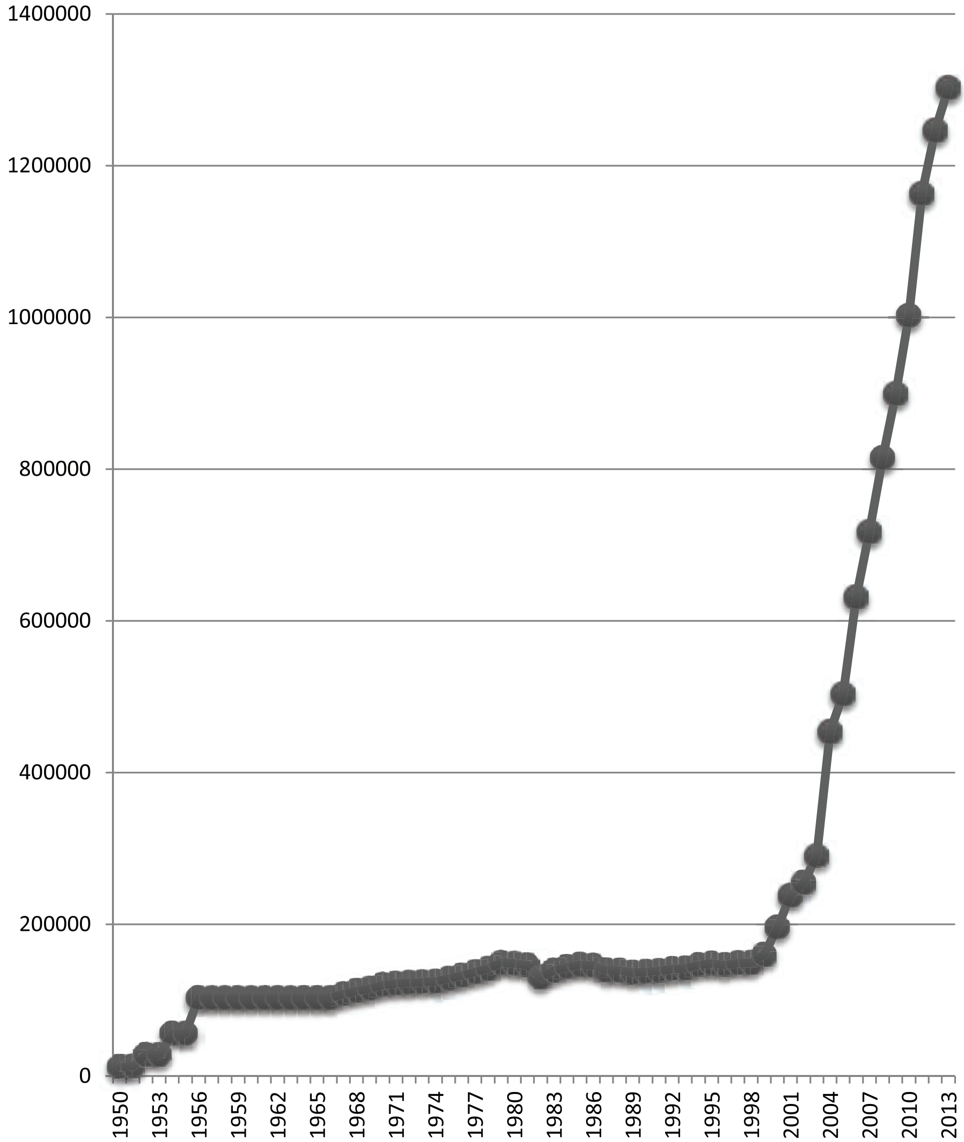

Figure 3.—The inland capture fish production (metric tons) of Myanmar (1950–2012) reported to the Food and Agriculture Organization of the United Nations. (Data source: FAO 2014a).

was unofficially explained as being caused by inclusion of unmonitored small-scale fisheries to the estimate. Previous reported estimates only covered those concessional fisheries that were monitored. This increase in Cambodia's fisheries production reported estimate was further substantiated as not being excessive by the findings of two reports published in 2007 and 2013 that relied on consumption survey data. The 2007 report is a fisheries information research project that commenced after the 1999 and 2001 reported estimates. This project, undertaken by the Mekong River Commission and the Cambodian Fisheries Administration, indicated that the Cambodia inland fishery harvested approximately 587,000 metric tons per year (Hortle 2007). This methodology included comparisons with information on household consumption as a means to estimate likely production, in the absence of compre-

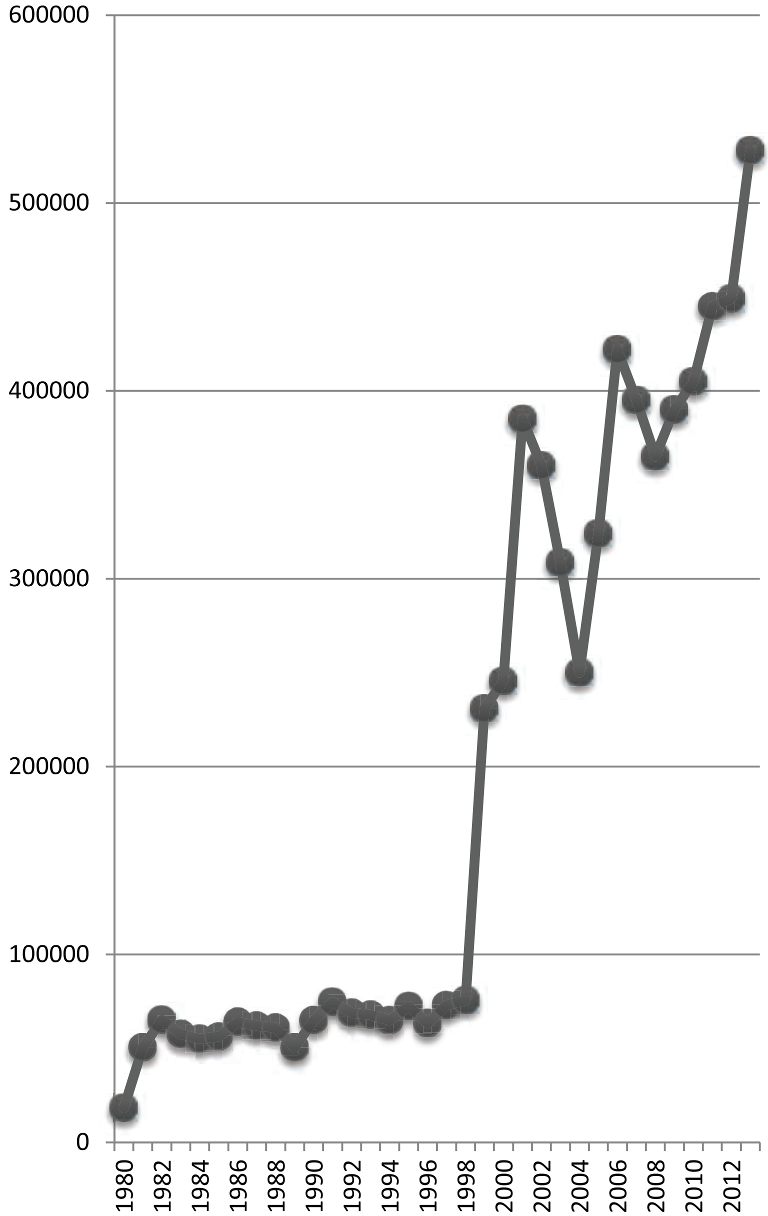

Figure 4.—The inland capture fish production of Cambodia reported to Food and Agriculture Organization of the United Nations (1980–2012). (Data source: FAO 2014a).

hensive inland fishery statistical monitoring. The 2013 report summarized the findings of a Cambodian consumption survey conducted during 2011–2012. This report indicated that inland fish constituted 71% of the total annual fish consumption (63 kg per capita per year), which gives an estimate of inland fishery production of 632,000 metric tons (IFReDI 2013). This production figure estimated from the reported consumption is higher than the currently inland capture fishery production figure reported to the Food and Agriculture Organization of the United Nations (FAO). This suggests that even the current estimates of Cambodian inland fishery production reported to FAO may still be underestimated.

Consumption Surveys May Explain Large Variations in Inland Fishery Production Estimates

Countries that have a statistical system for monitoring inland fisheries will derive an estimate of harvest that, depending on how it is derived, may drift off over time from the actual level of production. This drifting from the actual production level is an artifact of the approach used to derive the estimate. Countries, therefore, periodically reset the harvest estimate based on a validation methodology. Some validation methods that have been used include household consumption surveys, 5–10-year agricultural/population census, periodic fishery survey, and fishery sampling programs. Incidences of periodically reset harvest estimates can be seen when there are occasional instances of very large annual variations in the estimate reported by a country. These annual variations are so large that these cannot be easily explained as natural variability in production level resulting from climatic variations. Occurrences of reset have been noted in the reported inland fisheries catches for several countries in Asia by Lymer and Funge-Smith (2009). An example of where this may be occurring is in India's reported inland fishery production (Figure 5). During the period 1950 to 2012, there are 13 instances of an interannual variation of more than 20% and four instances where the interannual variation is greater than 40%. This is indicative of where the reported inland fishery production rises or decreases by such a substantial amount that cannot readily be explained by natural environmental or biological variability or the level of fishing activity. This is illustrated by the lack of coincidence of the large variation years with reported drought years, where a substantial decrease in the production might be expected in the subsequent year. Thus, India, may be applying a validation method, such as data from household consumption survey or other method, to reset its production estimate.

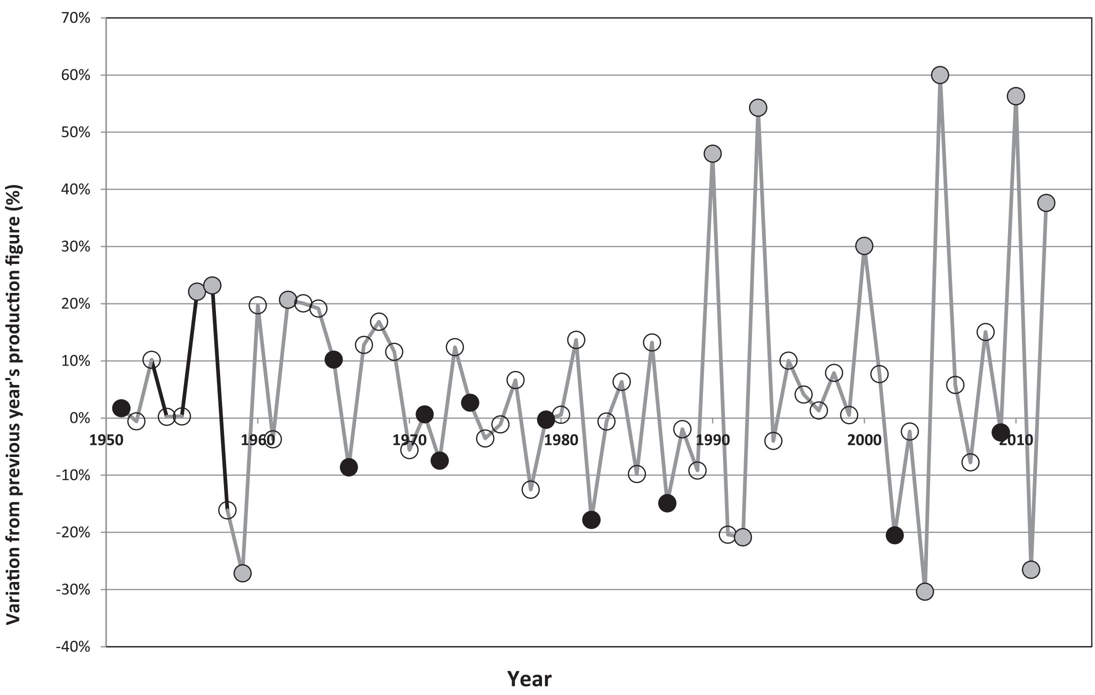

Figure 5.—Graph of between-year variations in inland fishery production for India (expressed as percentage change from previous year). Gray circles represent variation of more than 20%. Black circles represent drought years. (Data source: FAO 2014a).

Consumption Surveys May Prevent Inland Fishery Production from Being Misreported as Aquaculture Production

The contribution of inland fisheries to diets and local economies may be undervalued when inland fishery harvests are incorrectly attributed to aquaculture production. This incorrect attribution may lead to fish production from aquaculture being overestimated, the result being that aquaculture is given unjustified prominence as the principal source of fish production in the country. The policy ramifications of this are that investment and development effort may be misdirected into promotion of aquaculture rather than sustainable management of inland fisheries.

In Laos, there is relatively good agreement between the food balance sheets (18.2 kg per capita per year, 2007) and the consumption estimate from the fourth Laos expenditure and consumption (Department of Statistics 2010) household survey (19.1 kg per capita per year). This agreement breaks down when the source of fish is considered. The Lao expenditure and consumption survey indicates that the inland capture fishery provides approximately 88% of the fish consumed. The inland fishery and aquaculture statistics reported to FAO, which form the basis of the food balance sheet estimate, indicate that inland capture fisheries only provide 25% of total national production, with the bulk of production attributed to aquaculture.

Laos does not have a comprehensive inland fishery monitoring system, and even aquaculture production is an area-based estimate. In this example, it appears that inland fishery harvest is being grossly underestimated and that aquaculture production estimates are possibly inflated. The use of household surveys offers a means to validate the sources of production and even check the likely level of production reported. In the case of Lao PDR, where there are relatively limited imports and exports, the methodology can be considered to be reasonably reliable compared with estimations based on production areas and their assumed productivity.

Consumption Surveys Have Limitations

In the examples provided above, consumption survey data have been used to provide an alternative estimate of fish consumption to validate reported inland fishery harvest. In many cases, household surveys may provide information that is not sufficiently detailed to be used to reliably estimate inland fishery harvest. Common reasons for this are as follows:

- Survey questions may not distinguish between the sources of fish. The surveys can typically distinguish between freshwater and marine fish (on the basis of the species). In many cases household surveys cannot distinguish whether the fish consumed was produced from capture fishery or aquaculture;
- It is difficult to distinguish between consumption of locally caught fish and imports, particularly near borders;
- Respondents are often unaware of the source of the fish they purchase;
- Anadromous species (e.g., Hilsa *Tenualosa ilisha*, Asian Seabass [also known as Barramundi Perch] *Lates calcarifer*) and catadromous species (e.g., mullet, prawns *Macrobrachium* spp.) may be caught in freshwater, brackish-water, and marine environments, and the location of the fish at time of capture may not be distinguished. This is a particular challenge in assessing fisheries in the large tropical river delta areas (e.g., Ayerwaddy, Mekong, and Bramaputra), as well as inland brackish and freshwater lagoons (e.g., Songhkla Lake, Hue Lagoon).

Household consumption surveys are known to have weaknesses associated with their data collection process, such as follows:

- Surveys rely on recall of consumption and this may lead to underestimation and overestimation errors;
- The survey respondent may be quite unaware of the consumption of other household members, and often underreport; and
- Well-structured consumption surveys record consumption of different forms of

fish (e.g., fresh, frozen, fillets, canned, dried, smoked, and sauce) and, unless corrections are made, will underestimate fish production. To circumvent this, all weights must be converted to fresh weight equivalents, allowing for losses due to parts not eaten.

Consumption Surveys Can Reveal Much about Inland Fisheries in Cases Where National Monitoring Systems Are Not in Place or Where Subnational Detail Is Lacking

Although consumptions surveys cannot deliver fishery trend data on annual basis, they may indicate long-term trends in the source of production and even the species consumed. They can indicate the differences in consumption habits of rural and urban populations (Needham and Funge-Smith 2015).

Consumption surveys offer an insight into variations in subnational fish consumption and, as a proxy, fish production. The main value of the consumption survey is to act as a means of validating estimates of inland fishery production in situations where an effective fishery monitoring system is not in place. These may also allow a means to estimate the hidden production of small-scale, diffuse household fishing, which may not be captured in existing statistical monitoring systems, and act as a means of resetting gross overestimates or underestimates of fish production.

Conclusion

In situations where consumption surveys are considered to be the best approach to estimate or validate inland fisheries harvest, improvements could be made by

- Undertaking a 4-monthly or quarterly validation survey to correct for seasonality variations;
- Structuring the survey to collect data throughout an annual cycle to reduce recall errors by respondents;
- Improving questions to resolve the disaggregation between aquaculture and capture harvest; and
- Including a 5-yearly consumption survey alongside or in between other national fishery surveys.

Without improving information about inland freshwater harvests, the real value and importance of inland fisheries remains hidden and, more importantly, greatly undervalued.

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The Value of Tanzania Fisheries and Aquaculture: Assessment of the Contribution of the Sector to Gross Domestic Product

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Abstract.—The socioeconomic importance of the Tanzanian inland water and small-scale marine fishing industry and aquaculture sector in the country's development cannot be understated. With a coastline of 1,450 km^2 and richly endowed with natural water bodies, the fishing industry plays a fundamental role in food security, sustainable livelihoods, and poverty reduction. However, the fishing industry and aquaculture sector's contribution has been underestimated in past years; hence, it is not fully recognized as an economic sector that contributes significantly to the country's gross domestic product (GDP). The published value of the fishing industry and aquaculture sector contribution to the GDP is not reported holistically. The GDP contribution of the fish harvesting sector of the fishing industry is estimated by the National Bureau of Statistics as part of the agricultural gross product (AGP), in accordance with the System of National Accounts (SNA). The AGP accounts for only the value of the fish harvesting sector's activities, whereas the economic contributions of postharvest-related activities are accounted for under other sectors like manufacturing. This study focused on providing appropriate information about the overall value of the fishing industry and aquaculture sector. A production approach method was used to evaluate value-added contributions to the national GDP. The analysis found that the fishing industry and aquaculture sector's contribution to the GDP in 2011 was 3.07% as compared to the published GDP of 1.4%. This difference suggests that the fishing industry and aquaculture sector's contributions to GDP may have been underestimated by a factor of 2.2 and indicates that a postharvesting processing sector plays a significant role in GDP contribution. These findings provide a different perspective on how to calculate fishing industry and aquaculture sector contribution to the GDP from the existing structure of economic activity classification set by the SNA. To complement this information, the study also summarizes the contribution of the fish harvesting, postharvest processing and aquaculture sectors to employment. This study also calls for improved data collection and information related to the fisheries' postharvest activities. At the policy level, there is a need to rethink and prioritize development of the fishing industry and aquaculture sector in Tanzania.

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Introduction

Background and overview of the Tanzania fishing industry

Tanzania lies just south of the equator and covers an area of about 947,300 km^2 (CIA 2012). The country is rich in water resources; about 62,000 km^2 is covered by various water bodies that include the three largest lakes in Africa, diverse river systems, numerous wetlands, and a coastline of 1,424 km long along the western Indian Ocean (EAF-Nansen Project 2012).

The fishing industry[1] is economically and socially significant to the country, and it plays a fundamental role in food security, sustainable livelihoods, and poverty reduction. The inland and small-scale marine fish harvesting sectors officially contribute around 1.4–1.6% of the national gross domestic product (GDP; Planning Commission 2012; Figure 1). The fishing industry also contributes about 10% of the country's total exports from fish and fishery products (Ministry of Livestock and Fisheries Development 2012) and provides about 27% of the total protein intake in the country (FAO 2007).

[1] Fishing industry refers to the fish harvesting and postharvesting processing sectors.

Overview of the aquaculture sector in Tanzania

Aquaculture in Tanzania is a fast-growing sector that provides national food security and supports livelihoods for people living along the coast and inland areas. There are about 17,847 fish farmers in Tanzania, of which 14,750 fish farmers are involved in freshwater fish farming and 3,097 in mariculture (Ministry of Livestock and Fisheries Development 2012). Annual farmed fish production is estimated at 3,628.5 metric tons, which is about 0.98% of the average annual fish landings.

The decline of capture fisheries harvest from inland and territorial waters, coupled with the ever increasing demand for fish, has created an urgent need to promote aquaculture development in the country (F. A. Sobo, paper presented at the Workshop on Fisheries and Aquaculture in Southern Africa: Development and Management, 2006). The government has developed the National Aquaculture Development Strategy, which sets the framework for promoting commercial aquaculture

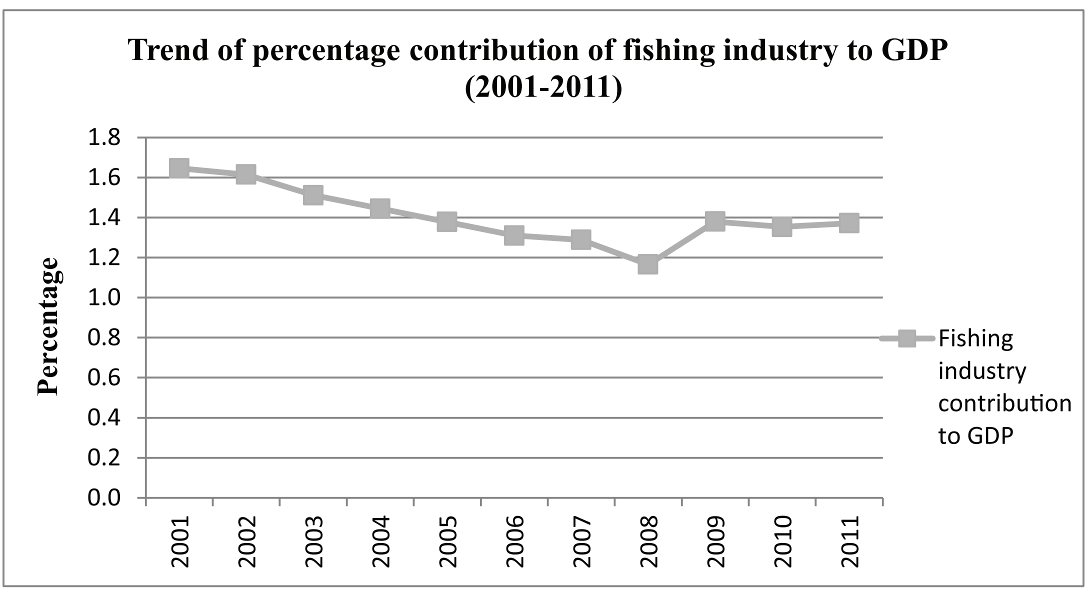

Figure 1.—Trend of percentage contribution of fish harvesting sector to national gross domestic product (GDP) from 2001 to 2011 (Planning Commission 2012).

in Tanzania (Ministry of Livestock and Fisheries Development 2008).

Contribution of the fishing industry and aquaculture sector to the gross domestic product

Though not fully recognized as major contributors to the GDP, the fishing industry and the aquaculture sector are important contributors to many national economies across African countries. In terms of food security, revenue generation, and employment derived from activities related to these sectors, both the capture fisheries and aquaculture sectors continue to be of fundamental importance, as can be seen by the tonnage and value produced (World Bank 2012).

In Tanzania, the contribution of the fishing industry and aquaculture sector to GDP is published by the National Bureau of Statistics. The calculation is based on the System of National Accounts; however, it incorporates only the GDP of the fish harvesting sector while related postharvest activities are considered under the manufacturing section (UN 2008).

The fish harvesting and aquaculture sectors are clearly an important direct source of employment (FAO 2007). A study by the World Bank indicated that the contribution to the GDP created by postharvest activities in some African countries can be high, making up more than 50% of the fishing industry's contribution to the GDP (World Bank 2012). Therefore, it is in the interest of the Tanzanian fishing industry to understand the fish harvesting, postharvest processing, and aquaculture sectors' contribution to the national GDP.

The GDP is the sum of economics of each sector to the performance of the whole economy within a country in a year, or a given period of time (Timmer 1992). A sector can contribute directly and indirectly to the economy (Cai et al. 2009). According to *National Accounts: A Practical Introduction* (UN 2003), there are three approaches to calculate GDP (UN 2003):

- Production approach,
- Expenditure approach, and
- Cost or income approach.

The most direct and common way to estimate GDP of the three approaches is the production approach through estimation of gross added value (UN 2003).

The present study applied the production approach to estimate the economic contributions of fish harvesting (production), postharvest activities, and employment generated by the sectors. The production approach estimates the GDP by assessing the gross value added of each economic activity in the national economy. Gross value added is an economic measure of the value of goods and services produced in an area, industry, or sector of an economy (UN 2003). It measures the increase in income after the costs of intermediate inputs into the production have been deducted.

Significance of the study

There is a knowledge gap in the Tanzania Fisheries Development Division regarding the contribution to GDP from the whole value chain of the fishing industry and aquaculture sector to the national GDP.

So far, there has never been a study conducted to estimate the whole value chain of the Tanzanian fishing industry and aquaculture sector contribution to the national GDP.

This study attempts to fill in critical knowledge gaps in understanding the fishing industry's and aquaculture sector's economic importance to the country. The results of this study should challenge existing perspectives of the marginality of the fishing industry and aquaculture sector in developing countries and should give attention to policy makers to prioritize development support to the fishing industry and aquaculture sectors.

The main objective of this study is to provide appropriate information about the overall value of the fishing industry and aquaculture sector.

The specific objectives of the study are

- to provide accurate information about the contribution of the fishing industry and aquaculture sectors to the GDP,
- to provide specific information about the employment generated by the fishing industry and aquaculture sector, and

- to improve fisheries data collection related to the required components for calculation of the GDP.

Methods

Data collection

The study was conducted between January and March 2012. Information was collected from the fish harvesting, postharvest processing, and aquaculture sectors and licensing. Information related to employment for each of these sectors was also collected and analyzed. The primary data collection involved direct field observation, focus groups, and structured interviews with fishers, fish farmers, and processors. The interview was distributed across Lake Victoria, Lake Tanganyika, Lake Nyasa, minor freshwater bodies, and marine territorial waters. Field work mainly occurred at the Kirumba fish market, Kayenze and Igombe landing sites for Lake Victoria; Kibirizi and Korongwe landing sites for Lake Tanganyika; and Ferry fish market, Masoko-pwani and Mikindani landing sites for the marine water, while information for processing was obtained from Vic Fish Ltd and Nile Perch Fisheries Ltd fish-processing plants. The interviews were conducted by fisheries officers from the Tanzania Fisheries Development Division and the Local Government Authority.

For the fish harvesting and aquaculture sectors' questionnaire, a total of 120 fishers and fish farmers were interviewed, and these formed a representative sample for the study; 44% of the fishers interviewed were from Lake Victoria, 30% from Lake Tanganyika, and 26% from marine territorial waters. Information about the employment provided by the fish harvesting and aquaculture sectors was also collected.

For postharvest processing and employment in the postharvest sector sections, 230 processors were interviewed about this sector's economic contribution and related employment. To obtain a representative sample for the study, respondents were randomly sampled (gender-representative). About 69 of the processor respondents interviewed were from Lake Victoria, 64 from Lake Tanganyika, 58 from marine water, and 39 from industrial processing plants. The information obtained for each sampled landing site, market, and processing plant was extrapolated based on the total number of smoking kilns, drying racks, frying facilities, and processing plants for industrial processing provided from frame survey reports.

The licensing section of the questionnaire gathered information from the Fisheries Annual Statistics Report 2011 (Ministry of Livestock and Fisheries Development 2012), specifically about the total number of licensed fees, which consisted of a fishing license fee, fishing vessel's license fee, and the vessel registration fee.

Primary data collection about the fish harvesting, aquaculture, and postharvest processing sectors and licensing and information about employment was complemented by secondary data sourced from the Fisheries Annual Statistics Report 2011 (Ministry of Livestock and Fisheries Development 2012), and frame survey reports for Lake Victoria (Ministry of Livestock and Fisheries Development 2010); Lake Tanganyika (Ministry of Livestock and Fisheries Development 2010); and marine waters (Ministry of Livestock and Fisheries Development 2009).

The data collected from the fish harvesting, postharvest processing, and aquaculture sectors and licensing were compiled and analyzed in Microsoft Excel.

Questionnaire

A standard questionnaire developed by the Food and Agriculture Organization of the United Nations (FAO) and the New Partnership for Africa's Development NEPAD-FAO Fish Programme (de Graaf and Garibaldi 2014) was used to collect data on the economic contribution and employment of the fishing industry and aquaculture sector. The questionnaire was divided to address all of the fishing industry and aquaculture sectors, and information was gathered from the relevant subsectors (Table 1).

The information gathered for the fish harvesting and postharvest processing sectors and licensing was further organized by fishing unit. Four classifications were used for the marine small-scale fisheries and the inland small-scale fisheries subsectors (Table 2).

Table 1.—Information collected in the questionnaire was organized by fishing industry and aquaculture sectors. The type of information gathered for each sector is summarized below.

No.	Sector	Subsector	Information type
1	Fish harvesting	Inland small-scale fishing Marine small-scale fishing	Annual landings, production costs (cost of purchasing gear, etc.); price of catches at landing site
		Employment	Information about employment in this sector was also gathered.
2	Aquaculture	Pond farming tilapia Cage farming tilapia Pond farming catfish Tank farming catfish Others	Number of farms, number of ponds per units, production areas, total annual production, annual production density, average farm gate prices, total gross product value, cost of fish production by production type
		Employment	Information about employment in this sector was also gathered.
3	Postharvest processing	Inland small-scale fishing Marine small-scale fishing	Quantity of fresh fish that goes for three postharvest processing types: processing by fishmongers, industrial processed, and artisanal-local processed. Processed fish may consist of smoked, dried, salted, gutted with head on, and gutted with head off.
		Employment	Information about employment in this sector was also gathered.
4	Licensing	Inland small-scale fishing	Number of fishing units by type of fishery, annual license fees per vessel, and licensing fees by type of fishery

Assessing the contribution of the fishing industry's sectors and aquaculture sector to the gross domestic product using the production approach

Assessing gross domestic product by production approach.—The GDP was estimated for each fishing industry's sectors by using the production approach using equations (1)–(5):

$$\text{GDP} = \text{GVA} + \text{Taxes} - \text{Subsidies} \tag{1}$$

$$\text{GVA} = \text{GPV} * \text{VAR} \tag{2}$$

$$\text{GPV} = \text{Total landings} * \text{Vessel fish price}/\left(\text{Farm gate fish price for aquaculture}\right) \tag{3}$$

$$\text{VAR} = (\text{GPV} - \text{Production cost})/\text{GPV} \tag{4}$$

$$\text{Production cost} = \text{Sum of all operating costs (fees, licenses, fuel, maintenance, and repair costs)} \tag{5}$$

Table 2.—Classification of fishing units for the inland small-scale fisheries and the marine small-scale fisheries subsector for the fish-harvesting sector, postharvest processing sector, and licensing (see Table 1).

No.	Type of fishery subsector	Fishing unit
1	Inland small-scale fisheries	Fishers without vessels/subsistence fisheries Nonmotorized dugouts/planked canoes Motorized small canoes (<10 m) Motorized large canoes/small-scale vessels (>10 m)
2	Marine small-scale fisheries	Fishers without vessesl/subsistence fisheries Nonmotorized dugouts/planked canoes Motorized small canoes (<10 m) Motorized large canoes/small-scale vessels (>10 m)

GVA = Gross value added
GPV = Gross production value, which is the total value of the catch landed
VAR = Value-added ratio

Production cost (capital cost) varies depending on the type of vessel or fishing unit. This study specified the annual production cost by type of fishing unit and included operating costs related to fees, licenses, fuel, maintenance, and repair costs.

Analysis and Results

Analysis of the gross value added of the fish harvesting sector

Analysis of gross production value for the fish harvesting sector.—The fish harvesting sector's GPV for the inland small-scale fisheries and the marine small-scale fisheries was calculated for each of their four fishing units (Table 2) using equation (3). The analysis indicated that the GPV for the fish-harvesting's inland small-scale fisheries, all fishing units combined, was 1,328,538,967,109 Tanzanian shillings (TSh)[2] and was TSh 231,748,777,100 for the marine small-scale fisheries.

Analysis of production cost by fishing units for the fish harvesting sector.—The production cost was calculated as shown in equation (5) and included the following information for each fishing unit (Table 3):

- Cost for purchasing fishing gears (spear, traps, gill nets, ring nets, etc.) and annual replacement cost of fishing gears;
- Cost for buying kerosene for lamps or lanterns and replacement cost for maintaining sail cloth; and
- Cost for boat repair; service charges for running generators and lamps; and cost for buying generators (KV6/KV4), fuel, and food.

Analysis of value-added ratios and gross value added of the fish harvesting sector by fishing units for both the marine small-scale fisheries and the inland small-scale fisheries.—The results of the analysis of the VAR (equation [4]) and GVA (equation [2]) for each fishing unit are presented in Table 4. The annual fishing landings for all fishing units combined is greater in the inland small-scale fisheries, with 290,474 metric tons and a GAV of TSh 820,850,440,209 than that of the marine artisanal/small-scale fishing subsector (Table 4).

Analysis of gross value added of the postharvest processing sector

Gross value added (equation [2]) was also applied to analyze GVA for the postharvest processing sector. The calculation considered the whole processing value chain of fish after being landed and the conversion factors of the processed products to standardize the weight of fresh fish used in the GVA calculation (Table 5). The following variables were collected:

[2] US$1 is equivalent to TSh 1,620.48 (2011).

Table 3.—Production cost of the fish-harvesting sector for the marine small-scale and the inland small-scale fisheries (exclusive labor cost and capital cost).

Fishing units	Annual production cost of the fishing (harvesting) sector in Tanzanian shillings (exclusive labor, capital)
Marine small-scale fisheries	
Fishers without vessels/subsistence fisheries	60,000
Nonmotorized dugouts/planked canoes	1,970,500
Motorized small canoes (<10 m)	27,052,000
Motorized large canoes/small-scale vessels (>10 m)	83,392,800
Inland small-scale fisheries	
Fishers without vessesl/subsistence fisheries	60,000
Nonmotorized dugouts/planked canoes	1,970,500
Motorized small canoes (<10 m)	27,052,000

Table 4.—The average gross value added of fish-harvesting sector by fishing units for the marine and inland small-scale fishing subsectors in 2011. TSh = Tanzanian shillings.

Fish-harvesting sector landings	Annual landings (metric tons)	Gross product value per vessel (TSh)	Annual production cost in TSh (exclues labor, capital)	Value added ratio	Gross added value (TSh)
Marine small-scale fishing subsector					
Fishers without vessel/ subsistence fisheries	5,059	3,031,647	60,000	1.0	20,828,272,200
Nonmotorized dugouts/ planked canoes	23,237	13,942,862	1,314,000	0.9	81,807,146,400
Motorized small canoes (<10 m)	7,118	110,459,172	27,286,000	0.8	28,459,168,000
Motorized large canoes/ small-scale vessels (>10 m)	15,178	126,247,209	75,460,000	0.4	33,808,639,200
Total marine small-scale fishing subsector	50,592				164,903,225,800
Inland small-scale fishing subsector					
Fishers without vessels/ subsistence fisheries	2,033	8,678,783	60,000	1.0	8,480,882,958
Nonmotorized dugouts/ planked canoes	156,856	16,689,811	1,314,000	0.9	567,179,207,480
Motorized small canoes (<10 m)	73,490	41,281,258	27,286,000	0.3	158,084,475,371
Motorized large canoes/ small-scale vessels (>10 m)	58,095	101,406,599	75,460,000	0.3	87,105,874,400
Total inland small-scale fishing subsectors	290,474				820,850,440,209

Table 5.—The conversion factors applied to the types of fish-processing methods and fish-processed products. (Source: FAO 1997, Annex I.1).

Types of processing	Conversion factor	Weight of processed fish obtained from 100 kg of fresh fish
Smoking	62%	62
Drying	41%	41
Salting	50%	50
Gutted head on	83%	83
Gutted head off	67%	67

- Quantity of catches used by the three postharvest categories;
- Conversion factor from live weight to processed product;
- Fresh fish or processed product price to calculate the GPV;
- Production cost (excluding labor and capital cost) to calculate the VAR; and
- GVA for the three postharvest categories.

The result shows that a GVA of TSh 10, 992,013,694 was obtained from the postharvest-processing sector activities (Table 6).

Analysis of gross value added from licensing

The questionnaire collected information of licensed fees per vessel for inland small-scale fishing, marine small-scale fishing, marine industrial locally based fishing, and marine industrial foreign-based fishing. License fees in this section refer to those paid by local fishers to the central government and local government authorities, the following are three types of licenses fees paid by local fishers:

- Fishing license fee equivalent to US$10/year,
- Fishing vessels license equivalent to US$10/year, and
- Vessel registration fee equivalent to US$10/year.

Items covered in the licensing section of the questionnaire were number of fishing units by type of fishery, license fees (local currency)

Table 6.—The gross value added (GVA) and value-added ratio (VAR) of postharvest processing sector activities by fishing unit for marine and inland small-scale fisheries. TSh = Tanzanian shillings.

Fish processing by fishing unit	VAR fresh fish	GVA fresh fish (TSh)	VAR industrial processed	GVA industrial processed (TSh)	VAR artisanal processed	GVA artisanal processed (TSh)
Marine small-scale fishing subsector						
Fishers without vessels/ subsistence fisheries	0.1	2,234,919,712			0.1	117,627,353
Nonmotorized dugouts/ planked canoes	0.1	9,724,671,527	0.1	186,825,231	0.1	864,415,247
Motorized small canoes (<10 m)	0.1	1,435,583,862	0.0	877,566,214	0.1	364,110,252
Motorized large canoes/ artisanal vessels (>10 m)	0.1	2,135,505,204	0.0	2,643,958,824	0.1	352,881,990
Total marine small-scale fishing subsector		15,530,680,304		3,708,350,269		1,699,034,842
Inland small-scale inland fishing subsector						
Fishers without vessels/ subsistence fisheries	0.1	898,216,897			0.1	47,274,574
Nonmotorized dugouts/ planked canoes	0.1	65,644,122,084	0.1	1,261,120,052	0.1	5,835,033,074
Motorized small canoes (<10 m)	0.1	14,820,690,630	0.0	9,059,824,173	0.1	3,759,003,946
Motorized large canoes/ artisanal vessels (>10 m)	0.1	8,173,926,260	0.0	10,120,099,179	0.1	1,350,702,101
Total inland small-scale fishing subsector		89,536,955,871		20,441,043,403		10,992,013,694

per vessel per year, licensing fees (local currency) by type of fishery, and total license fees (local currency).

Data about production cost (equation [5]) and VARs (equation [4]) were not calculated for the licensing section, and therefore, the GVA (equation [2]) was regarded to be same as the GPV (equation [3]). The analysis provided a GVA of about TSh 2,797,626,000 from the licensing activities (Table 7).

Analysis of aquaculture gross value added

The GVA for aquaculture was calculated using (equation (2)). The analysis indicated a GVA of TSh 19,876,186,000 (Table 8).

Gross value added and contribution to gross domestic product of the fishing industry

The overall GVA (equation (6)) and contribution to the GDP for the entire fishing industry and aquaculture sector were calculated by summing up the GVAs of the fish harvesting sector, the aquaculture sector, the postharvest processing sector, and licensing. The results are presented in Table 9.

$$\text{Overall contribution to GDP} = \begin{pmatrix} \text{GVA fish harvesting} \\ + \text{ GVA postharvest processing} \\ + \text{ GVA licensing } + \text{ GVA aquaculture} \end{pmatrix} \times \left(\text{Annual published GDP}\right) \tag{6}$$

The overall analysis of this study reveals that inland small-scale fisheries contributed 2.51% (Table 10) and aquaculture contributed 0.05% to the country's total GDP (Figure 2).

The result shows that total GVA for the fishing industry and aquaculture sectors are TSh 1,150,335,556,392, which represents a contribution of 3.07% to the country's GDP of TSh 37,532,962,900,000 (Table 11).

Employment

The fishing industry and aquaculture sector support livelihoods for many people in Tanzania by providing employment to fishers who engage on a full-time basis and through various fisheries-related activities, such as boat building, net making, local and industrial fish processing, fish trading, and fish farming (FAO 2007).

Employment through the fish-harvesting (marine small-scale fishing, inland small-scale fishing, and postharvest processing) and aquaculture sectors.—This study estimated the details of the employment generated by the fish harvesting, postharvest processing, and aquaculture sectors from inland freshwater bodies and marine water. The Fisheries Annual Statistics Report 2011 (Ministry of Livestock and Fisheries Development 2012) provided information about the number of full-time and part-time fishers. The study found that full-time em-

Table 7.—The gross value added of licensing activities for the inland and marine small-scale fisheries.

Fishing unit categories	Licensing value (Tanzanian shillings)
Marine small-scale fisheries	
Fishers without vessels/subsistence fisheries	109,340,400
Nonmotorized dugouts/planked canoes	319,784,400
Motorized small canoes (<10 m)	13,572,000
Motorized large canoes/artisanal vessels (>10 m)	25,318,800
Total marine small-scale fisheries	468,015,600
Inland small-scale fisheries	
Fishers without vessels/subsistence fisheries	30,700,800
Nonmotorized dugouts/planked canoes	1,803,344,400
Motorized small canoes (<10 m)	374,914,800
Motorized large canoes/artisanal vessels (>10 m)	120,650,400
Total inland small-scale fisheries	2,329,610,400
Total (inland and marine)	2,797,626,000

Table 8.—Gross value added (GVA) for the aquaculture subsector.

Item	No. of farms	No. of ponds/ units	Area[a]	Annual production[b]	Production rate[c]	Farm gate price[d]	Gross value (total)	Gross value per area or unit[e]	Production cost per ha or unit[f]	Value added ratio	GVA
Pond-farned tilapia	16,318	19,469	584	8,761	15,002	5,000	43,805,000,000	75,008,562	42,500,000	0.4	18,985,000,000
Cage-farmed tilapia											
Pond- farmed catfish	1	3	0	3	10,000	3,000	8,820,000	30,000,000	11,000,000	0.6	5,586,000
Tank-farmed catfish											
Others	1,306	246	22	443	20,127	5,000	2,214,000,000	100,636,364	60,381,818	0.4	885,600,000
Total	17,625			9,207			46,027,820,000				19,876,186,000

[a] In hectares.
[b] Metric tons per year.
[c] Kilograms per hectare per year, or metric tons per year.
[d] Local currency per kilogram per unit per year.
[e] Local currency.
[f] Exclusive labor, capital, and taxes.

Table 9.—Summary of gross value added (GVA) and contribution to gross domestic product (GDP) of fish harvesting, postharvest processing, licensing, and aquaculture. Each sector's GDP contribution is divided by the country's total GDP of 37,532,962,900,000 Tanzanian shillings (TSh) to calculate the percentage.

GVA by subsector or processing type, as applicable	Subsector total (TSh)	Summary of GVA by sector	Sector total (TSh)	Sector contribution to GDP (%)
GVA marine small-scale fishing subsector	164,903,225,800	Fish harvesting	985,753,666,009	2.63%
GVA inland small-scale fishing subsector	820,850,440,209			
GVA fresh fish processing-by-fishmongers type	105,067,636,175	Postharvest processing	141,908,078,383	0.38%
GVA industrial-processed (TSh) type	24,149,393,672			
GVA Small-scale, local processed (TSh) type	12,691,048,536			
GVA marine small-scale fishing subsector licensing	468,015,600	Licensing	2,797,626,000	0.01%
GVA inland small-scale fishing subsector licensing	2,329,610,400			
GVA aquaculture	19,876,186,000	Aquaculture	19,876,186,000	0.05%
Total	1,150,335,556,392	Total	1,150,335,556,392	3.07%

Table 10.—Summary of gross value added (GVA) and contribution to gross domestic product (GDP) of fish harvesting, postharvest processing, and licensing of inland small-scale fisheries. Each sector's GDP contribution is divided by the country's total GDP of 37,532,962,900,000 Tanzanian shillings (TSh) to calculate the percentage.

Category	Value (TSh)	Contribution to GDP in %[a]
GVA inland small-scale fishing subsector	820,850,440,209	2.19
GVA inland small-scale fishing subsector licensing	2,329,610,400	0.01
GVA inland small-scale postharvest processing subsector	120,105,481,280	0.31
Total inland small-scale GDP (2011)	943,285,531,889	2.51
Total published country GDP (2011)	37,532,962,900,000	

[a] Inland small scale GVA ÷ Total published country GDP*100.

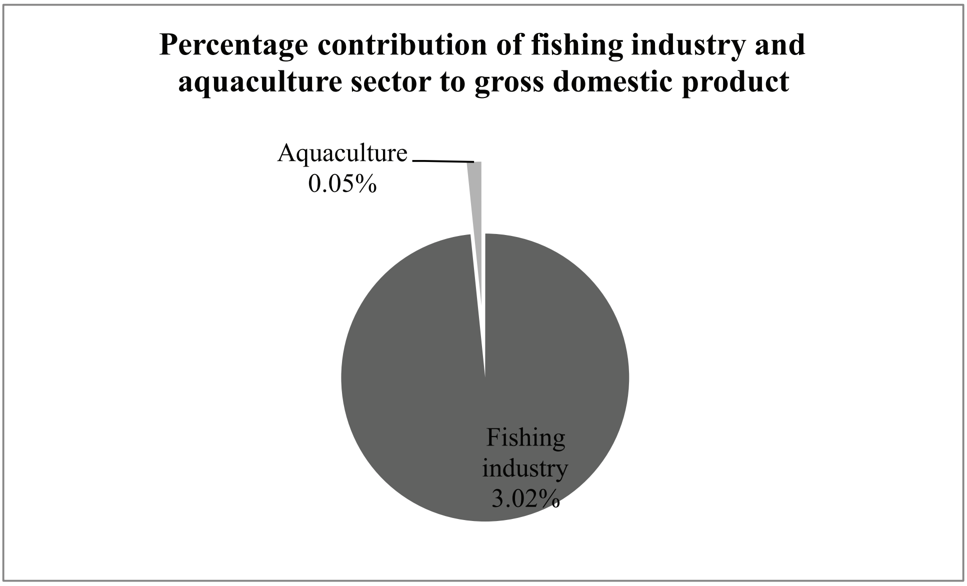

Figure 2.—Summary of contribution to gross domestic product (GDP) of the fishing industry (combing the GDP from the fish harvesting sector, postharvest processing sector, and licensing), and aquaculture sector (Ministry of Livestock and Fisheries Development 2012).

ployment in these three sectors was 185,683 jobs (Table 12).

The results shows that a higher percentage of male fishers compared to female fishers participate in fishing activities from both the inland small-scale fishing subsector (98.3% and 1.7%, accordingly) and the marine small-scale fishing subsector (89.6% and 10.4%, accordingly).

Employment through postharvest processing.—The analysis indicated that 257,339 people are employed in industrial processing from inland and marine small-scale fisheries (Table 13).

The analysis of employment in fisheries processing activities shows that high percentages of females are engaged in processing activities. About 53.1% are involved in processing activities from inland water, while in marine water, female participation was 51.8%.

Discussion

The fishing industry (fish harvesting sector, postharvest processing sector, and licensing) and aquaculture sector have very important

Table 11.—Published country gross domestic product (GDP) for fisheries that considers only fish-harvesting-related activities and the calculated GDP for the entire fishing industry that includes the fish harvesting, postharvest processing, and aquaculture sectors, and licensing (Planning Commission 2011). TSh = Tanzanian shillings.

Category	Value (TSh)
Total published country GDP (2011)	37,532,962,900,000
Published fisheries GDP (2011)	514,201,579,404
Total GDP this study	1,246,668,025,992
Published contribution to GDP (Published fisheries GDP ÷ Total published country GDP*100)	1.37%
This study contribution to GDP (This study’s fishery industry and aquaculture sector GDP ÷ Total published country GDP*100)	3.07%

Table 12.—Employment data for fish-harvesting sector (inland small-scale fisheries and marine small-scale fisheries) and aquaculture in 2011. The number of fishers and percentage of male and female fishers are included (Ministry of Livestock and Fisheries Development 2012).

No.	Item	No. of employees	% male	% female
1	Inland small-scale fishing subsector	141,206	98.3	1.7
2	Marine small-scale fishing subsector	36,321	89.6	10.4
3	Aquaculture	8,156	32.6	67.4
	Total	185,683		

implications for the social and economic welfare of fishers, processors, fish farmers, and the nation at large. However, the national policies overlook the sectors due to their assumed relatively minor economic contribution to the national GDP.

This study examines the value of the fishing industry and aquaculture sector. The study is expected to change the general perception of the fishing industry and aquaculture sector in Tanzania, and it is very likely that similar lessons can be drawn in other African countries with regards to the importance of these sectors.

The present study found that the fishing industry and aquaculture sector have a GDP contribution of up to 3.07%, which is an aggregate of the fish harvesting sector (2.63%), postharvest processing sector (0.38%), licensing (0.01%), and the aquaculture sector (0.05%). Clearly, the study shows that, the fish harvesting sector was the key contributor to the GDP. The analysis also indicated that inland small-scale fisheries contributed about 2.51%, followed by marine small-scale fisheries at 0.51% and aquaculture at about 0.05%. The inland small-scale fisheries have a high contribution because of their high production volume, output value, and provision of employment, when compared to marine fisheries and aquaculture.

The fishing industry and aquaculture sectors have always been important for supporting employment in the country. The study shows that the postharvest processing sector supports more than half of the employment in the fishing industry and aquaculture sector, with an overall approximation of 257,339 fish processors. This is more than 64 times the estimate of the 2007 country fisheries profile (FAO 2007) of about 4,000 processors. This study reports a much higher estimate of processors because fisher communities are increasingly engaging in fish-processing activities. Furthermore, the results noted that fish-processing activities were almost equally distributed between males and female (48.8% and 51.2%, respectively). Though the small-scale local processing sector is relatively small, it has great potential for generating employment opportunities and contributing to poverty alleviation, particularly for women. A study in Gambia by the United Nations Conference on Trade and Development indicated that fish-processing activities, a light type of work, are female-intensive (UNCTAD 2014), whereas the total fish harvesting sector (inland small-scale fishing and marine small-scale fishing) was

Table 13.—Total number and percentage of female and male processor employment in industrial processing, inland, and marine small-scale processing activities in 2011.

No.	Item	No. of employees	% male	% female
1	Industrial processing	44,327	49.2	50.8
2	Fresh fish processing by fishmongers	190,324	53.1	46.9
3	Small-scale local processing	22,688	51.8	48.2
	Total	257,339		

male-dominated, with 98.3% and 89.6% of the total employment being male for inland small-scale fishing and marine small-scale fishing, respectively.

This study indicated that the present estimates for contributions of the fishing industry and aquaculture sector to the GDP are conservative; the actual values are likely to be higher as found in this study. The study did not include GVA from the exclusive economic zone (EEZ) because it was not possible to establish the production costs and average vessel price/kg from industrial tuna purse seiners and long-liners that would be used in calculating the GVA. Doing so would have increased economic benefits from the fishing industry. Still, this study has provided new and comprehensive information of the value of Tanzanian fishing industry and aquaculture sector, which is of importance for managing fisheries resources in Tanzania.

On a national scale, the results suggest an urgent need to improve fishing industry and aquaculture sector data collection, specifically including the value of GDP contribution of the postharvest processing sector to the GDP value of the fishing industry and aquaculture sector. The contribution of the value of the fishing industry to the GDP emphasizes the importance of investing in development projects for this industry, such as the construction of a fishing harbor that will handle fish from commercial fishing vessels operating in the EEZ. The availability of a fishing harbor will contribute to the optimal use of existing EEZ resources through employment, income generation, food security, revenue, and foreign earnings.

At the policy level, this finding should catalyze national and policy maker to reexamine the existing policies that neglect the fishing industry and aquaculture sectors and contribute to prioritizing support for fisheries development in Tanzania.

Challenges and Recommendations

The results indicate the importance of the fishing industry and aquaculture sector in Tanzania in the provision of employment and contribution to the country's economy. However, some of the challenges encountered during the course of the study include lack of data available to calculate GVA marine industrial fishing (tuna long-liners and purse seiners) from the EEZ.

Therefore, it is recommended that

- Detailed studies be carried out to include GVA of the industrial tuna long-liners and purse seiners from the EEZ, as well as to determine employment from other post harvest activities (boat building, net mending, etc.);
- Construction of fishing harbor be carried out that will optimize utilization of the existing EEZ resources, thus benefiting the country;
- The Ministry of Livestock and Fisheries Development and the National Bureau of Statistics review the calculation of the sector to GDP; and
- Data about the economics of fishing units and employment in the local and industrial processing sector be incorporated in data collection forms.

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Economic and Social Analysis of Artisanal Fishermen in Taraba State, Nigeria

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Abstract.—Major rivers and flood ponds in Taraba State, Nigeria are important to the livelihood of fishers and their households. But overfishing and destructive fishing practices have occurred in some of the water bodies. This study examined the characteristics of fishing operations, benefits derived from these operations, nonfishing-based sources of livelihood, and the benefits of fishers and community involvement in the management of these water bodies. A multistage sampling method was used to select fishing households for this study. The first stage involved selecting local government areas from the four Taraba State Agricultural Development Programme (ADP) zones. Then, fishing households were proportionally selected from the eight local government areas selected in the first stage. A total sample of 200 fishers was used for the study. Qualitative data were obtained from fisheries government agency extension personnel and leaders of the fishing communities through in-depth interviews. Quantitative data were collected through structured questionnaires. The data were analyzed using descriptive statistics, profit margin analysis, *t*-test, and analysis of variance. Types of fishing gear used, fish species caught, and benefits derived from fishing, as well as other sources of livelihood, were documented. Taboos and beliefs used by the fishers aimed at preserving the fish species and environment of the water bodies were included in the paper. Result of the profitability analysis showed significant differences in fishers' incomes based on whether or not the fishers owned an outboard engine, and between ADP zones. The paper recommends that a management process involving multi-stakeholders should be implemented to better attain sustainable livelihoods for fishers and food security.

Introduction

The fishery sector in Nigeria is a major source of income for those inhabiting communities near water bodies. According to Ovie and Raji (2006) fisheries contribute to the nation's economy in terms of food security, employment, poverty alleviation, foreign exchange earnings, and provision of raw materials (protein source) for animal feed industries. Fish harvested constitute about 41% of the total animal protein intake by the average Nigerian; hence, there is great demand for fish in the country (FMARD 2011). The Federal Ministry of Agriculture and Rural Development (FMARD 2012) reported that artisanal fisheries have continued to dominate Nigeria's domestic total fish supply of 968,283 metric tons by contributing more than 69% (668,754 metric tons). In terms of direct-use values, inland fisheries contributed 45% (297,836 metric tons) of the total artisanal fish harvest in 2012. Artisanal fishers use a small amount of capital and energy, as they make short fishing trips in small (if any) canoes close to shore, and the fish harvested are mainly for local consumption (FAO 2015). Even though their fishing operations are small-scale in nature,

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their activities yield nutritional benefits and fish food supply for domestic consumption by the poor (Fregene 2002).

Taraba State is drained by four major rivers, Benue, Donga, Taraba, and Ibi, and their tributaries. They arise from the Cameroon Mountains, draining almost the entire length of the state in a north and south direction to link up with the Niger River (Oruonye and Bashir 2011). The state has about 500,000 ha of water bodies and 142 natural ponds (TSEEDs 2004, cited by Oruonye 2014). These rivers and ponds in Taraba State are major sources of livelihood for the fishers and their households. However, few studies have been conducted at the household level, and there are few management strategies targeting the conservation of the fisheries resources, especially in fishing communities in Taraba State.

This study examined characteristics of fishers, fishing operations, and fish species caught; other sources of livelihood and benefit derived; profitability of fishers; and community involvement in the management of the water bodies. Two null hypotheses in the study were tested as follows:

1. Annual profit among fishers with outboard engines and those without outboard engines are not significantly different, and
2. Significant differences do not exist between the artisanal fishers operating in the four Taraba State Agriculture Development Programme (ADP) zones.

Study Area

Taraba State is located northeast of Nigeria and has a total land area of 54,428 km^2 extending between latitudes 6°25’N and 9°30’N and longitudes 9°30’E and 11°45’E. It is bounded in the north by Gombe State, in the west by Bauchi and Benue states, in the east by Adamawa State, and on the south by Cameroon (Oruonye and Bashir 2011).

The state is located within the guinea savanna zone (Taraba State Agricultural Development Programme 2009). It has a tropical climate characterized by well-marked wet and dry seasons. The wet season usually starts from April and ends in November with an annual rainfall varying from 1,250 mm in the north to 2,500 mm in the southern part of the state, with an annual average temperature of 26.7°C to 27.8°C, with lower temperatures occurring towards the south (TSADP 2009). The dry season begins in November and ends in March. The estimated population is 2,280,483 (NPC 2006). It is a multiethnic state inhabited by a number of ethnic groups: Tiv, Kuteb, Chamba, Jukun, Hausa, and Fulani, who are predominantly farmers and engaged in different types of activities such as fishing, hunting, local craft, and tailoring.

Methods

A survey was conducted in which a multistage sampling technique was used (Villareal et al. 2004). In the first stage, 8 of the 16 local government authorities (LGAs) were selected from the four ADP zones: North, South, Central, and Gambo. These eight LGAs have high concentrations of fishing activities (Figure 1). In the second stage, fishing households were proportionally selected from the eight LGAs using the list of registered fishers collected from the Divisional Fisheries Office, Taraba State Ministry of Agriculture and Natural Resources (MANR), Jalingo. A sample size of 200 fishing households, which is 0.46% of the total number of fishermen in the eight LGAs (43,933), was used for the study (Table 1).

Qualitative data were gathered using semistructured questionnaires during oral interviews with extension personnel of fisheries government agency, and from leaders of the fishing communities through in-depth interviews (J. E. Olawoye, University of Ibadan, unpublished data). Quantitative data were collected from structured questionnaires administered to fishers by extension agents through individual surveys (Callerholm Cassel and Jallow 1991; Villareal et al. 2004)

Statistical analysis and hypothesis testing

Data were analyzed using descriptive and inferential statistics. Descriptive statistics included frequency, percentages, and profit margin analysis. *T*-test and analysis of variance were the inferential statistics used to

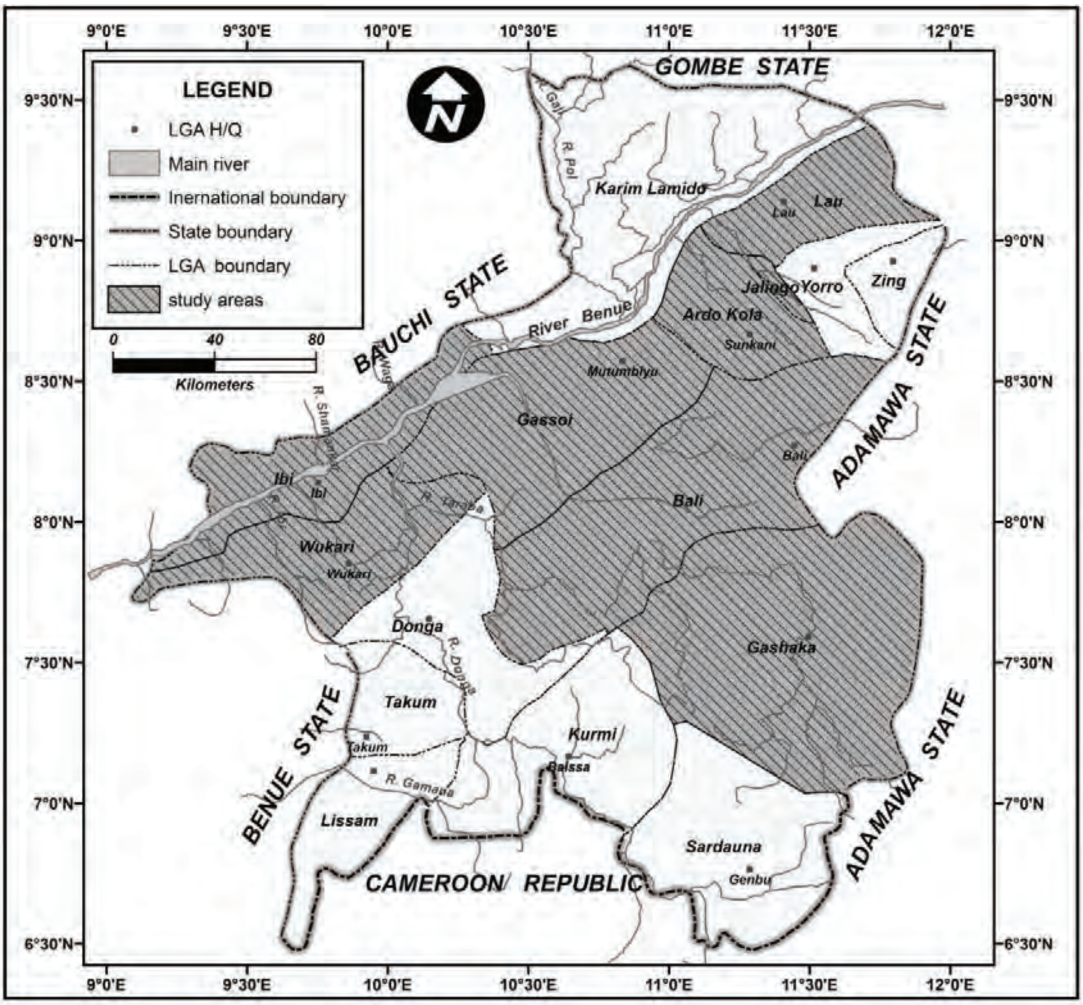

Figure 1.—Sampled local government area in Taraba State.

Table 1.—Population and sample of fishers in local government areas (LGAs) selected within each Agriculture Development Programme (ADP) zone for this study.

ADP zones	LGAs	Total number of registered fishers in each LGA	Number of fishers selected from each LGA
North	Mayo-Ranewo	7,864	36
	Lau	7,556	34
	Jaling	4,553	21
South	Ibi	8,769	37
	Wukari	5,632	25
Central	Bali	4,331	23
	Gassol	3,978	18
Gambo	Gashaka	1,250	6
	Total	**43,933**	**200**

test the hypothesis. Profit margins were analyzed using

$$TC = TFC + TVC, \tag{1}$$

$$TR = PQ, \tag{2}$$

$$GM = TR - TVC, \text{ and} \tag{3}$$

$$\pi = TR - TC, \tag{4}$$

where

TC = Total cost (naira [₦]);
TFC = Total fixed cost (₦);
TVC = Total cost (₦);
TR = Total revenue (₦);
P = Unit price of fish catch (₦);
Q = Quantity of fish catch
GM = Gross margin
π = Total profit/net returns (₦);

The independent-samples *t*-test was used to detect a significant difference between mean profit earned by fishers with outboard engines and mean profit earned by fishers without outboard engines. Analysis of variance under a general linear model, in which the errors are distributed normally, was used to test for any differences in the mean profit earned by fishers in all the ADP zones. The analysis focused on fixed effects of profitability of fishers within the zones. SPSS Statistics version 20 (IBM, Bethesda, Maryland) was used for the analysis.

Results

Socioeconomic characteristics of fishers

Presented in Table 2 are the socioeconomic characteristics of fishers interviewed. The sample showed that all are male (100.0%) and the majority are married (98.5%). Almost half of those who are married have one wife (45.5%). The majority of the fishers are within the age bracket of 23–50 years (71.5%) and have completed at least primary education (76.5%). In terms of household size, 48.5% of the fishers have between 11 and 20 family members. The primary source of livelihood is fishing during the dry season (91.0% of fishers) while during the wet season, about 52.5% of fishers were actively involved in both fishing and farming.

Fishing operations

The majority of fishers interviewed had more than 10 years (95.9%) of fishing experience (Table 3). Most of the fishers are full-time fishers (54.0%) and have at least one wooden canoe. Only 24 fishers (12%) have canoes with outboard engines. Gill nets of various sizes are used. Both family and hired labors are also used.

Some fishers fished year round, primarily in the Benue and Taraba rivers, with their fishing activity being more concentrated during the dry season (November–March), which is the main fishing season. Other water bodies that are fished include the Bali, Dongai, and Suntai rivers. Fishers also fish in natural ponds that can be as large as 5–50 ha and owned by families of the ruling or royal houses/community leaders. These natural water bodies were fished between January and March or between April and May. Examples are Bemba Lake, which is more than 4 km^2 in size, and Marami Lake and Goje Pond, which are 4 km^2 in size in the Wukari LGA.

Major fish species caught include *Tilapia* spp., Nile Tilapia *Oreochromis niloticus* (also *T. nilotica*), *Clarias* spp., Nile Perch *Lates niloticus*, Aba *Gymnarchus niloticus*, Bayad *Bagrus bajad*, and *Synodontis* spp. Others reported by a few of the fishers include Moon Fish *Citharinus citharus*, African Bonytongue *Heterotis niloticus*, *Heterobranchus* spp., *Labeo* spp., Elongate Tigerfish *Hydrocynus forskahlii*, Torpedo Robber *Alestes macrophthalmus*, clupeids, *Protopterus* spp., *Polypterus* spp., Electric Catfish *Malapterurus electricus*, and *Mormyrus* spp.

Household value of fisheries resources

In the 16 LGAs, located within the four ADP zones, there are more than 52,535 fishers households registered with the Taraba State Ministry of Agriculture and Rural Development who earned their living solely from inland fisheries (TSADP 2010). Fisheries resources are valuable to the fishers based on the benefits derived. According to the fishers interviewed, income generated from fishing was used mainly for meeting basic needs such as food, health care, and clothing. Fishing gear

Table 2.—Demographic characteristics of fishers.

Demographic characteristics	Number	%
Sex		
Male	200	100.0
Female	–	–
Age		
≤30	13	6.5
31–40	60	30.0
41–50	70	35.0
51–60	41	20.5
>60	16	8.0
Educational level		
None	47	23.5
Primary school	47	23.5
Secondary school	75	37.5
Tertiary	31	15.5
Religion		
Christianity	119	59.5
Islam	81	40.5
Marital status		
Single	3	1.5
Married	197	98.5
Widow	–	–
Number of wives		
None	3	1.5
1	85	42.5
2–4	112	56.0
Household size		
1–5	33	16.5
6–10	70	35.0
11–15	43	21.5
16–20	29	14.5
>20	25	12.5
Occupation in dry season		
Fishing	182	91.0
Farming	5	2.5
Fish farming	2	1.0
Fishing and civil servant	2	1.0
Fish, farming, and fish farming	1	0.5
Occupation in wet season		
Fishing	65	32.5
Farming	24	12.0
Fish farming	2	1.0
Fishing and farming	105	52.5
Fishing and civil servant	3	1.5
Fish, farming, and fish farming	1	0.5

Table 3.—Characteristics of fishing operations.

Characteristics	Number	%
Fishing experience in years		
1–10	7	5.4
11–20	28	21.5
21–30	44	33.8
31–40	30	23.1
>40	21	16.2
Period of fishing operation		
Full-time	108	54.0
Part-time	45	22.5
Seasonal	29	14.5
Occasional	18	9.0
Canoes		
1–2	108	54.0
3–5	35	17.5
Outboard engine		
15 hp	10	5.0
25 hp	8	4.0
40 hp	6	3.0
Fishing gears		
Gill net		
1.5"	14	7.0
2"	50	25.0
3"	93	46.5
4"	97	48.5
5"	84	42.0
6"–8"	7	3.5
Cast net	54	27.0
Drag net	44	22.0
Hook and line	49	24.5
Long line	10	5.0
Traps	6	3.0

and farming supplies were also bought. Some fishers used the money to pay school fees of their children; others built houses and bought cars and motorcycles.

Profit analysis

Table 4 and Figure 2 revealed that fishers with outboard engines earned at least twice as much as those without outboard engines. Annual depreciation for fishing gear was calculated for 5 years.

Communities involvement in management of the water bodies and evidence of conflict

A mixed management strategy is used in the management of the water bodies. Rivers and streams have open-access fisheries that are mainly under the control of the state and federal departments of fisheries. The ruling or royal house families own and manage the natural ponds and lakes. The main interaction that exists between the multiple users of the water bodies in Taraba State is that of compromise, not conflict.

During the fishing season, fishers from other fishing villages are invited to fish and required to pay a tax to fish in the natural ponds and lakes. Fishers from the village and other villages that are not owners of the ponds must pay to fish. A group of fishers could be asked to pay as much as ₦300,000 or more to set gill nets to fish in a pond or lake owned and managed by the ruling or royal house families.

Table 4.—Cost and profit of fishers in Naira. The average annual profit per fishers is calculated by taking the total income from fish sales and subtracting the variable costs (labor, fuel, and other costs) and the fixed cost (annual depreciation of fishing gear calculated over 5 years).

	Annual		Monthly	
	Canoes with outboard engines	Canoes without outboard engines	Canoes with outboard engines	Canoes without outboard engines
Income from fish sales	440,750.00	217,735.16	36, 729.17	18,144.60
Less variable cost:				
Labor	32,125.00	22,744	2,677.08	1,895.33
Fuel	34,187.04	–	2,848.92	–
Other	16,062.50	11,372.16	1,338.54	947.68
Total variable cost	82,374.50	34,116.48	6,864.54	2,843.04
Average gross margin	366,708.83	183,618.68	30,559.07	15,301.56
Less fixed cost:				
Annual depreciation of fishing gear	61,536.67	19,91778	5,128.08	16,598.15
Average annual profit per fisherman	313,446.78	163,700.00	26,120.56	13,641.67

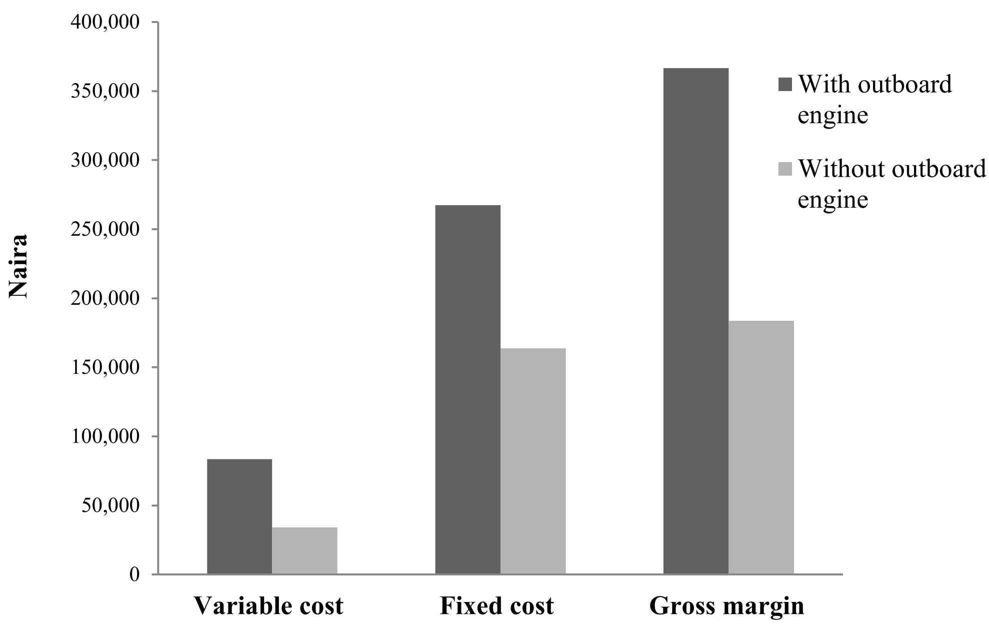

Figure 2.—Annual costs and gross margin of artisanal fishers with and without outboard engines in Taraba State.

When a ruling or royal house family charges ₦300,000 to fish in their pond or lake for 3 months, the amount charged is shared among the group of fishers. The fishers are of the opinion that, in general, a payment of ₦15,000 per fisherman is too much. Traditional management of the ponds and lakes by the ruling and royal houses families has improved over time. Since 1991, owners of the ponds have learned from the Taraba State MANR Divisional Fisheries Office to remind fishers to adhere to fisheries laws before the start of every fishing season. An example is that they are not allowed to use undersized mesh sizes, chemicals, or plant poisons.

Despite the presence of traditional (ruling and royal house families) and government management system, overfishing and destructive practices still occur in some of the water bodies. The information collected through interviews with the divisional fisheries officer of the Taraba State MANR Divisional Fisheries Office and some executive members of fishermen cooperative societies reveal that these destructive practices include unrestricted numbers of fishers using gill nets and drag nets, use of chemicals such as Gamalin 20, unrestricted draining of pools, and erection of permanent barriers to trap migratory fishes. Members of fishery cooperative societies in Bali keep watch over the waters and have arrested offenders for polluting the waters with chemicals. These offenders were sent to court, and officers of the Taraba State MANR Divisional Fisheries Office prosecuted them.

Taboos and beliefs

From the 200 fishers interviewed, it was observed that fishers believe in several taboos and some of them are targeted at females. For example no woman menstruating is allowed to touch the nets or come into the canoe. Other taboos exist: slippers or shoes are not allowed in the canoe, some fishers believe that they should wash their face and feet before entering the canoe, the use of charms and drunkenness are not allowed when fishing, eating *Heterobranchus* spp. is believed to cause yellow fever. The only taboo aimed at preserving the fish species and environment of the water bodies is that fishers are forbidden from using chemicals to harvest fish.

Challenges of fishers

Major complaints of the fishers interviewed included the lack of funds to buy fishing gear and lack of government assistance. Moreover, fishers also complained that fisheries officers are neither available to patrol water bodies to enforce fishing regulations nor to train fishers. Other challenges encountered by the fishers that were mentioned during the interviews include the constant receding of water levels due to the drying up of Benué River and insufficient fish to catch. Some fishers complained of being chased by hippopotamuses while fishing in Benué River. According to the fishers, the use of traps and fences was considered a possible reason for the reduction in fish catch because both migratory adult spawners and fingerlings are caught.

Test of hypothesis

The results of the analysis revealed that there was significant difference between mean profit earned by owners of canoes with outboard engines and owners of canoes that did not have outboard engines (t = 2.560, df = 27.200, P = 0.016). Profitability analyses across ADP zones were also significantly different (ANOVA: F = 2.751; df = 3, 196; P = 0.044).

Discussion

For those in Nigeria that live near water bodies, fishing is a major source of livelihood (Townsley 1998; Fregene et al. 2003; FAO 2015). Fish caught provide food security and income. The income generated from fishing is used to purchase food, housing, education, assets, and health for the fishing households (Chiwaula and Witt 2010).

Several other studies have revealed that the average net margin for fishers with outboard engines was higher than for those without (Fregene et al. 2003; Olademeji et al. 2014). But contrary to this study, some studies found that the fishers without outboard engines earned a larger profits because they had higher returns on investment, as well as a higher operating margin, than fishers with outboard engines (Olademeji et al. (2014). Inoni and Oyaide (2007) also observed that although small-scale fishing was found to be profitable, the low operating margin, particularly among fishers with outboard engines was a concern, due to the high cost of production, dwindling catches, and the need to safeguard the livelihood of fishing-dependent people in coastal communities.

Community involvement in governance

Scudder and Connelly (1985), cited by Ita (1993), identified two major categories of management of traditional riverine fisheries in the Amazon basin, middle Zambezi River, and Kafue floodplains. One management category consisted of inadvertent or unintentional management strategies, such as water tenure, ritual prohibitions, taboos, and magic. The other management category consisted of intentional strategies that include gear restrictions, closed seasons, and floodplain intensification (increased ownership). Both these management categories are common in the northern states of Nigeria. However, Ovie and Raji (2006) observed that mixed systems involve the participation of both the unintentional management category, as represented by the traditional ruler and royal house families, and the intentional management category, represented by the modern government administrations that operate in fishing communities.

Ita (1993) reported that in some northern states, such as Sokoto Rima and Kano, flood ponds and stagnant pools of seasonal rivers belong to all the communities, and permission to engage in fishing is often announced by the sarkin ruwa or the “chief of the fishermen,” who has the power to authorize and stop fishing in different ponds and at appropriate times. This approach, although similar to closed seasons found in government management approaches, is directed more at protecting the interests of part-time fishers who engage in full-time farming during the rainy season and return to fishing at the end of the farming season. The focus of this restriction is not for conservation of fisheries resources, but to ensure that every member of the community has an equal chance of benefiting from the resource.

Challenges of fisheries resources conservation and fish data

The conservation of fisheries resources becomes a challenge when there is a lack of alternative sources of livelihood during the dry season. An increase in the number of fishers will invariably result in smaller catches per fisher and therefore a lower profit margin. Aragón-Noriega (2009) is of the opinion that in an area that has a well-established fishing tradition, enforcing a permanently closed season could produce severe social disturbance. The enforcement of fishery laws and regulations requires determined political commitment on the part of government and adequate legislative and financial support (Amiengheme 1993).

Despite the importance of fish catch data, funding for the development and maintenance of fisheries statistics at the federal level has been decreasing since 1992, while demand for fish catch data is growing. Fishery data are not available in nearly all of the states in Nigeria, likely due to poor funding and insufficient personnel to collect and collate such data (NAERLS and NPAFS 2010). Inadequate fisheries statistics collected especially for inland fisheries are from many unlicensed, part-time, and seasonal operators (Fregene and Bamiduro 2006). The Federal Ministry of Agriculture and Rural Department (2012) recorded 11,862 metric tons of fish production for Taraba State. This is quite low based on the available water bodies in the state. Chiwaula and Witt (2010) observed that there is an acute lack of relevant research and data about the socioeconomic value of small-scale fisheries to fish-dependent households and communities. As a result, communities depending on artisanal fisheries are often marginalized or ignored in national and regional development policies.

Recommendation

The artisanal fisheries require a dynamic partnership approach that will use traditional skills, indigenous knowledge, local institutional arrangements, and resource stewardship. Jallow and Njie (2004) therefore advised that these elements be complemented with national governments, providing an enabling environment, scientific advice, legislation, monitoring, and control, and surveillance, among other types of assistance. Capacity building among both government personnel and local stakeholders must therefore be developed and promoted.

Government officials are limited in number and lack mobility and finances to enforce regulations. Executive members of the existing fishery cooperatives, however, can further be empowered to monitor, control, and conduct surveillance on water bodies. This is because they are located in every LGA and have members in almost all the fishing communities. They will be more committed because the water bodies provide their livelihood.

A critical issue is the need for the Nigerian government to adequately fund data collection for fish catches and socioeconomic variables (Fregene and Bamiduro 2006). Timely and accurate information is essential for effective management. In a situation where the government fails, nongovernmental organizations, together with executive members of livelihood associations, for example, have been effective in aquaculture data collection.

There is a need to enlighten traditional rulers and members of the fishing communities to minimize conflict and increase the understanding of the value of the fisheries.

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Livelihood and Poverty among Fishers and Nonfishers in the Hirakud Reservoir Region, Odisha, India

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Abstract.—A field study was conducted to understand the livelihoods and poverty incidence among fishers and nonfishers (farmers and farm laborers) residing around the Hirakud reservoir in Odisha State, India. About 14,500 fishers in 159 villages are dependent on Hirakud fisheries. The fishers belonged to several socially diversified groups, including traditional fishing castes (42%) and agricultural and artisanal castes. Both fisher and nonfisher households had diversified occupational profiles. The literacy rate among fishers was 62%, as compared to nonfishers (83%). While housing, per se, did not differ, basic amenities (sanitation, electricity, and drinking water) were far better among nonfishers and correlated significantly with higher educational status and expenditures for health and well-being. Forty-two percent of fishers belonged to the fishing caste and most of the nonfishers (74%) belonged to other castes (i.e., not part of the fishing, agriculture, or artisanal caste). Inequality and poverty studies revealed that fishers were poorer than nonfishers as per both the standards of India's Planning Commission and the World Bank. This finding was also supported by the results of a poverty gap index and a Watts index, which highlighted a greater depth of poverty among fishers than nonfishers. The incidence of extreme poverty was 21% among fishers and 3% among nonfishers when using the cut-off per capita expenditure of purchasing power parity (PPP) US$1.25/d, and the incidence rose to 64% and 34%, respectively, when the cut-off line is PPP $2/d. Interestingly, as per Gini index values, income inequality was greater among nonfishers (0.215) and the average rural Indians (0.339) than the fishers (0.158).

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Introduction

The development of fisheries in reservoirs is a holistic function of ecology, fisheries, socioeconomics, and governance, with technology playing an intermediate role. Only a few studies have addressed this issue holistically, as most have studied only fisheries and ecology. Very little information exists about the reservoir fisheries in Odisha; details like fisheries management systems, fish production trends, utilization patterns, and socioeconomic status of fishing communities are not available as per the literature review. As per the survey data of the State Fisheries Department, Odisha has a total water spread of 256,000 ha in the form of major, medium, and minor reservoirs, and a total of 1,442 units of reservoirs were identified, covering an area of 197,198 ha, which contribute to the fish production of the state. There are three large reservoirs, Balimela in the district of Koraput (19,440 ha); Hirakud in the Sambalpur, Jharsuguda, and Bargarh districts (71,963 ha); and Rangali in the district of Dhenkanal (28,000 ha). Annual fish harvest from the Hirakud reservoir is 4,798 metric tons (2012–2013) with a yield of 84 kg/ha, which is consistent with the state average productivity of 83 kg/ha (computed by the authors from the compiled survey data). This paper focuses on the livelihoods, poverty, and inequality of fishers and nonfishers of the Hirakud reservoir in the region of Odisha. Nearly 14,500 fishers depend upon this reservoir for their livelihood. Odisha has significant reservoir resources; the extent of their use for fisheries and the potential for creating sustainable livelihood in distressed conditions and remote areas need to be understood. The socioeconomic status of fishing communities around the dam plays a very significant role in the development of reservoir fisheries. Livelihood study and analysis can reshape a program focusing on the livelihoods of people, and help make clear how a program fits in with livelihood strategies and how people's livelihoods are being enhanced or constrained. On this basis, recommendations for improvement interventions can be made (Ashley 2000). Poverty estimates will act as vital input to design, monitoring, and implementation of appropriate antipoverty policies. It is in this context that the following specific objectives are undertaken.

Objectives

The specific objectives of the study are (1) to understand the social, economic, and occupational profile of fishers and nonfishers; and (2) to analyze the inequality and poverty among fishers and nonfishers.

Methods

The present study was conducted in the Hirakud reservoir region of Odisha by the authors. The reservoir is divided into six geographical sectors. During the presurvey visit, information regarding the total number of villages in all sectors on the periphery of reservoirs, their fisher population details, religions, and caste details were assembled to build the sampling methodology. Five villages were selected representing all the stretches of the reservoir for study. Fishers' population of the village, major fishing activities, and fishers' membership in the cooperative society were also considered during the selection of villages for study. First-hand observations by transect walks through the villages in the reservoir periphery and interviews with key informants with the aid of a check list, a semistructured interview with respondents, and a focused group discussion were carried out. The sample size was 190, including fishers (120) and nonfishers (70).

Here, an independent sample *t*-test was used to differentiate among fishers and nonfishers on the basis of variables of continuous scale (age, family size, education, housing facilities, and housing amenities). A Mann–Whitney *U*-test was used to compare differences between two fishers and nonfishers when the dependent variable is either ordinal or continuous but not normally distributed (family type [e.g., nuclear family or joint family]; caste type [e.g., fishing caste, agricultural caste, artisanal caste, and other castes]).

Housing facilities and household amenities

To develop an index for housing facilities, four parameters were considered: house type, ownership status, house area, and cooking place. These four parameters were rated on a 4-point scale, with highest rank given to the better facilities. The combined scores were standardized to make them unit-free. To develop a household amenities index, five variables were selected and rated on a 3-point scale, including sanitation facility, drinking water, fuel used for cooking, lighting source, and mode of transportation. The same procedure applied for a housing facilities index was adopted to develop a household amenities index.

Inequality and poverty

Poverty analysis tools.—The extent of poverty was based on the monthly per capita expenditure of fishers and nonfishers. The poverty line was fixed as per the World Bank (i.e., poverty head count ratio at US$1.25/d, which is equal to Rs 19.8 in Indian currency [rupees; World Bank 2005] and poverty head count ratio at $2/d, which is equal to Rs 31.8 in Indian currency (World Bank 2005). A poverty line at $1.25/d indicates extreme poverty and a poverty line at $2/d was used to compare the status of poverty at the extreme poverty line ($1.25/d). A comparative study of the extent of poverty was also done using the poverty line value of India's Planning Commission (i.e., Rs 27.2/d [This is an Indian standard of estimating poverty line.]). A conversion factor was used to convert U.S. dollars to Indian rupees and the conversion factor for India is 15.9 (Average of conversion factor data of World Bank [2013] data for the years 2011, 2012, and 2013 has been considered for analysis by author.).

Poverty indices.—For the analysis of poverty, the head count ratio, poverty gap index, Lorenz curve, Gini index, and Watts index (Table 1; Haughton and Khandker 2011, Chapter 4) were used based on the consumption expenditure of fishers and nonfishers, but the Gini index was calculated from both income and expenditure. All these indices have been compared with the World Bank data (Haughton and Khandker 2011, Chapter 4).

Results

Social parameters

In the Hirakud reservoir region, most of the fishers (58.3%) and nonfishers (65.7%) are middle aged (i.e., 35–59 years). The mean age of fishers (43.36 years) was not significantly different from that of nonfishers (41.53 years). The majority of nonfishers (55.7%) had secondary education (6–10 years of education), whereas 38.3% of fishers were illiterate. There was a significant difference between the education level of fishers and nonfishers. Nearly 88% and 98% of fishers and nonfishers, respectively, belonged to nuclear families. Most of the fishers (73%) and nonfishers (88%) had a family size of less than five members. Nonfishers had better houses with more amenities than fishers (Table 2).

Caste type

Table 3 depicted the caste profile of people residing around the Hirakud reservoir. The people in the periphery of the reservoir belong to different caste types, like fishing caste, agricultural caste, artisanal caste, and other castes. Forty-two percent of fishers belonged to the fishing caste, and most of the nonfishers (75%) belonged to other castes. A Mann–Whitney *U*-test indicated that the *P*-value was 0.000, and there was a significant difference between fishers and nonfishers with respect to caste.

Economic profile

Occupation.—Fishers who live in the periphery region of the Hirakud reservoir had four types of occupation: (1) fishing only; (2) fishing and olericulture; (3) fishing and labor; and (4) fishing, olericulture, and labor (Table 3). The primary occupation was fishing and olericulture (45.8%) followed by only fishing (42.5%; Table 4). Only a few fishers were also employed in both olericulture and labor.

Most nonfishers were involved in agriculture (31.4%) and private industry (31.4%; Table 5). Many factories have been developed in the Sambalpur, Jharsuguda, and Bargarh districts, so many respondents were involved in

Table 1.—Poverty indices and their properties.

Poverty indices	Property	Formula
Head count index (P^0)	Measures the proportion of a population that is poor.	$P^0 = N_p/N$ N_p = number of poor N = total population (or sample)
Poverty gap index (PGI)	Measures the extent to which individuals fall below the poverty line as a proportion of the poverty line. PGI ranges in value from 0 (all individuals are above the poverty line) to 1 (all individuals are below the poverty line).	$\mathrm{PGI} = \frac{1}{N}\sum_{i=1}^{q}\left(\frac{z-y_i}{z}\right)$ q = number of individuals whose income falls below the poverty line z = poverty line for income or expenditure y_i = income/expenditure falling below the poverty line
Lorenz curve	Shows the actual quantitative relationship between the percentage of a population and the percentage of the total income/expenditure they received during a time period (year).	
Gini index (G)	Measure of inequality. G ranges in value from 0 (perfect equality) to 1 (perfect inequality).	$G = A/(A + B)$ A = area between line of equality and Lorenz curve B = area below Lorenz curve
Watts index (W)	Measures depth of poverty. W ranges in value from 0 (all individuals above the poverty line) to 1 (all individuals below the poverty line)	$W = \frac{1}{N}\sum_{i=1}^{q}\left[\ln(z)-\ln(y_1)\right]$ N = individuals in the population q = individuals whose income falls below the poverty line z = poverty line for income or expenditure y_i = income/expenditure

private industry. Only 15.7% of respondents among nonfishers were farm laborers (Table 5).

Expenditure pattern.—A comparative study of the monthly per capita expenditure shows how fishers, nonfishers, and rural Indians earn money to have the ability to provide a varied diet to their family. Table 6 depicts that monthly per capita expenditure of fishers as Rs 976, which is less than that of nonfishers (Rs 1315) and rural Indians (Rs 1189). Food accounted for 52% and 49% of expenditures of fishers and nonfishers, respectively, whereas for the average rural Indian, food accounted for 43% of expenditures during 2011–2012 (NSSO 2013). The expenditure on nonvegetable items among nonfishers was more than that of fishers and average rural Indians. Nonfishers were spending more on education (8%) than fishers (4%) and average rural Indians (4%). Expenditures on health for fishers and nonfishers were 4% and 5%,

Table 2.—Social parameters of occupational groups (N = 190). The P-value is provided, and whether the difference is significant (S) or nonsignificant (NS) is indicated.

Parameters	Measure	Fishers (N = 120)	Nonfishers (N = 70)	P-value
Age	Mean	43.36	41.53	NS (0.229)
Education	Mean	3.48	6.3	S (0.000)
Nuclear family	%	88.3	98.6	NS (0.012)
Family size	Mean	4.87	4.44	NS (0.090)
Membership in FCS/GP[a]	%	76.6	–	–
Housing facilities	Mean	0.564	0.626	S (0.000)
Housing amenities	Mean	0.368	0.497	S (0.000)
Male literacy rate	%	76.08	85.99	–
Female literacy rate	%	53.41	70.75	–
Total literacy rate	%	64.74	78.37	–

[a] FCS = Fishermen Cooperative Society; GP = Gram Panchayat.

respectively, which were less than that of average rural Indians (8%) (Table 6).

Inequality and poverty

Extent of poverty of occupational groups in the reservoir region.—"Poverty has been described by the International Bank for Reconstruction and Development (IBRD 2001) as a situation of 'pronounced deprivation in well-being,' and being poor has been described as 'to be hungry, to lack shelter and clothing, to be sick and not cared for, to be illiterate and not schooled.' Poor people are particularly vulnerable to adverse events outside their control. They are often treated badly by institutions of the state and society and excluded from voice and power in those institutions" (IBRD 2001). In India, the Planning Commission estimates the number and proportion of people living below the poverty line at national and state levels separately for rural and urban areas. It estimates poverty based on a large sample survey of household consumption expenditure carried out by the National Sample Survey Organization after an interval of approximately 5 years. The percentage of persons below the poverty line in 2011–2012 has been estimated as 25.7% in rural areas, 13.7% in urban areas, and 21.9% for the country as a whole. As per the Planning Commission's poverty line, there were more fishers (38%) falling below the poverty line than nonfishers (23%), and their average annual per capita expenditure (Rs 7,323) is less than that of nonfishers (Rs 8,770) (Table 7).

Lorenz curve and Gini index

For a comparison of the distribution of income, a Lorenz curve was drawn for fishers, nonfishers, and rural Indians based on the household per capita income. It shows the relationship between the percentage of the population and the percentage of per capita household income. For

Table 3.—Caste type of occupational groups in study area.

Caste type	Fishers (N = 120) Count	Fishers (N = 120) %	Nonfishers (N = 70) Count	Nonfishers (N = 70) %
Fishing caste	50	41.7	3	4.3
Agricultural caste	35	29.2	9	12.9
Artisanal caste	1	0.8	6	8.6
other caste	34	28.3	52	74.3
Mean rank	75.9		129.09	
Z-statistic	–6.882			
Asymptotic significance (two-tailed) or P-value	0.000			

Table 4.—Occupation of fishers in study area.

Occupation	Fishers (*N* = 120) Frequency	%
Fishing	51	42.5
Fishing and olericulture	55	45.8
Fishing and labor	9	7.5
Fishing, olericulture, and labor	5	4.2

Table 5.—Occupation of nonfishers in study area.

Occupation	Nonfishers (*N* = 70) Frequency	%
Farm labor	11	15.7
Agriculture	22	31.4
Private industry	22	31.4
Small business	15	21.4

fishers, it shows that the bottom 20% of the population has 13.3% of the total household per capita income (summation of numbers 1 and 2; Table 8), whereas the upper 20% of the population has 27.09% of the income (summation of numbers 9 and 10; Table 8). For nonfishers, the bottom 20% of people has only 10% of the income, whereas the top 20% of population has 38% of the income (summation of numbers 1 and 2 and summation of numbers 9 and 10, respectively; Table 8. This shows that there is less inequality or variation in the distribution of the income of fishers than that of the nonfishers and rural Indians (Figure 1).

The inequality in income distribution can be better understood from the values of the Gini index. It ranges in value from 0 (perfect equality) to 1 (perfect inequality). The Gini index value for fishers (0.137) is less than that of the nonfishers (i.e. 0.280). This Gini index

Table 6.—Monthly per capita expenditure of occupational groups in the study area. Rs = Indian rupees. Values in parentheses are percentage values. (Source: computed by author from the compiled survey data).

	Fishers (*N* = 53)		Nonfishers (*N* = 31)		India (rural)[b]
Average consumption	Quantity (kg or no.)	Value (Rs)	Quantity (kg or no.)	Value (Rs)	Value (Rs)
Food items					
Cereals(kg)	12.4	209.44	9.73	150.83	154
Pulses (Dal)/lentils (kg)	0.05	5.07	0.65	65.39	42
Vegetables, roots, and tubers (kg)	3.29	197.64	3.43	205.54	95
Milk and milk products (L)	1.76	31.7	2.41	48.1	115
Fruits (kg)	0.004	0.39	0.16	15.62	41
Eggs[a] (no.)	3.88	65.6	3.89	162.7	68
Meat[a] (kg)	0.31		0.32		
Fish[a] (kg)	7.23		1.3		
Food total	–	509.84	–	648.1	515
Nonfood items					
Education	–	40.9 (4%)	–	100.81 (8)	50 (4)
Clothing	–	75.53 (8%)	–	88.09 (7)	100 (8)
Entertainment	–	15.02 (2%)	–	22.7 (2)	76 (6)
Health	–	41.7 (4%)	–	60.91 (5)	95 (8)
Others	–	292.71 (305)	–	394.58 (30)	353 (30)
Nonfood total	–	465.86 (48)	–	667.09 (51)	674 (57)
Food and nonfood total	–	975.7	–	1,315.3	1,189

[a] Prices of eggs, meat, and fish have been combined for fishers and nonfishers due to limitations of data.
[b] Rural India information is from NSSO 2013.

Table 7.—Extent of poverty among fishers and nonfishers. Rs = Indian rupees. *N* = sample size of fishers and nonfishers having consumption expenditure details for calculation of poverty information. (Source: computed by author from the household survey data conducted by author).

	Fishers (*N* = 53)		Nonfishers (*N* = 31)	
Details of poverty status	Count	%	Count	%
Planning Commission's poverty line, Rs 27.2/d				
Below poverty line	20	38	7	23
Average	Rs 7,323		Rs 8,770	
Above poverty line	33	62	24	77
Average	Rs 13,166		Rs 15,657	
Poverty head count ratio at US$1.25/d (Rs 19.8)				
Below poverty line	11	21	1	3
Average	Rs 6,167		Rs 6,763	
Above poverty line	39	79	30	97
Average	Rs 12,224		Rs 14,346	
Poverty head count ratio at US$2/d (Rs 31.8)				
Below poverty line	31	64	11	35
Average	Rs 8,679		Rs 9,464	
Above poverty line	19	36	20	65
Average	Rs 14,736		Rs 16,652	

also shows more equality in distribution of income among fishers than that of the nonfishers.

Inequality and depth of poverty

A comparative study has been done on inequality and depth of poverty for fishers and nonfishers of the Hirakud reservoir region based on India's Planning Commission and the World Bank. The head count ratio only depicts the number of persons falling below the poverty line; it does not reveal the depth of poverty (Table 9). Therefore, a poverty gap index, Gini index, and Watts index were developed.

The poverty gap index, which ranges from 0 to 1, with a value of 1 indicating that all individuals are below the poverty line (Table 1), indicates that the incidence of poverty for nonfishers (0.002) is less than that of fishers (0.030), which is less than that of rural Indians (0.075) when applying the World Bank's purchasing power parity (Table 9). When the range of income distribution or expenditure among the individuals in the sample is very high, the pov-

Table 8.—Distribution of household income of fishers, nonfishers, and rural Indians.

		Income (Indian rupees)		% of income		
No.	% of population	Fishers	Nonfishers	Fishers	Nonfishers	Rural Indians
1	10	124,332	255,000	5.41	4.12	3.69
2	10	181,215	336,000	7.89	5.43	4.85
3	10	193,049	378,000	8.40	6.11	5.67
4	10	204,231	402,000	8.89	6.50	6.47
5	10	219,784	480,000	9.56	7.76	7.34
6	10	236,785	576,000	10.30	9.31	8.35
7	10	248,765	654,000	10.82	10.57	9.57
8	10	267,445	777,000	11.64	12.56	11.25
9	10	290,538	882,000	12.64	14.26	14.02
10	10	332,048	1,446,000	14.45	23.38	28.79

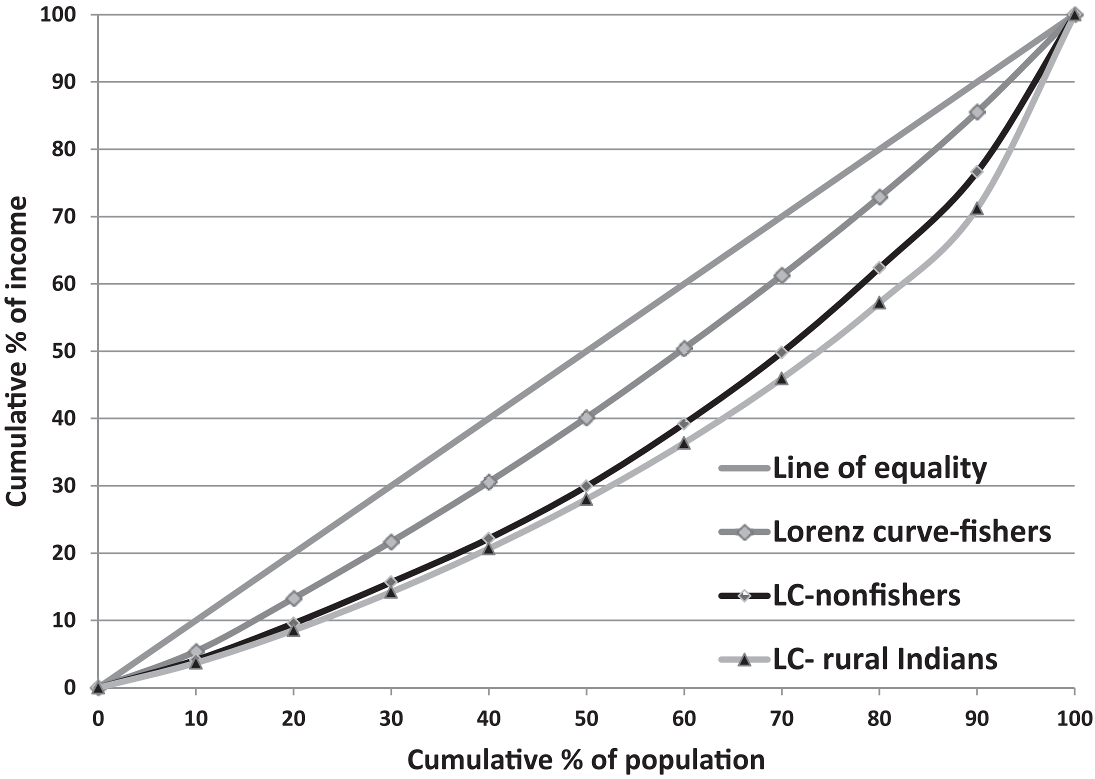

Figure 1.—Lorenz curve (LC) based on income and Gini index.

erty gap index is affected. However, this can be overcome by using a Watts index, which is computed by using antilogs. The results of the Watts index, which ranges from 0 to 1, with a value of 1 indicating that all individuals are below the poverty line (Table 1), revealed a greater depth of poverty among fishers (0.029) than nonfishers (0.002).

Discussion

This study focused on the socioeconomic aspects and occupational profile of fishers and nonfishers of the Hirakud reservoir region and also compared the inequality and poverty of fishers and nonfishers. The study found significant differences in economic characters between fishers and nonfishers, with fishers usu-

Table 9.—Inequality and depth of poverty. Rs = Indian rupees.

	Based on Planning Commission's poverty line (Rs 27.2/d)		Based on World Bank's purchasing power parity (poverty line = US$1.25/d [Rs 19.8/d])		
Inequality and depth of poverty	Fishers[a]	Nonfishers[a]	Fishers[a]	Nonfishers[a]	Rural Indians[b]
Head count ratio	0.377	0.132	0.208	0.032	0.327
Poverty gap index	0.104	0.026	0.030	0.002	0.075
Gini index	0.158	0.215	0.158	0.215	0.339
Watts index	0.127	0.033	0.029	0.002	0.091

[a] Computed from primary household data (monthly expenditure) collected by author.
[b] Source: World Bank.

ally being more poor than nonfishers. Although nonfishers had a higher level of inequality in income distribution than fishers, this was due to the diversified occupational profile of nonfishers (farm labor, farming, small business, and private job), resulting in a high range of income variation.

Nonfishers were found to be richer than fishers with a better standard of living. It was difficult to collect the actual income information of fishers and nonfishers through the household survey. To get the actual income details of fishers, income calculated from the daily fish catch details of each fisher could be used but may not be representative of the household. Furthermore, it was not possible to get the actual income details of nonfishers due to data limitation. Further efforts should be made to get more complete income information on fishers and nonfishers. This information about the livelihood of fishers can be used by policymakers, administrators, researchers, and client agents to form better livelihood strategies. Poverty estimates can also be helpful as a vital input to design, monitor, and implement appropriate antipoverty politics.

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Freshwater Fisheries Harvest Replacement Estimates (Land and Water) for Protein and the Micronutrients Contribution in the Lower Mekong River Basin and Related Countries

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Abstract.—Freshwater capture fisheries in the lower Mekong River basin (LMRB) contribute from 17% to 22% of the officially reported global inland capture fisheries catch. Several dams have been proposed on the Mekong River and its tributaries that will impact these fisheries. It has been estimated that the harvest from freshwater capture fisheries in the LMRB could decline by 880,000 metric tons in 2030 if all dam construction proceeds as planned.

To reflect the consequences of lost fisheries in the LMRB, we reviewed existing data and calculated the contribution freshwater fisheries make to human protein, nutrient, and mineral requirements. We further calculated how much additional land and water would be required to replace lost fish protein in the LMRB with four other animal protein sources: beef, chicken, pork, and milk.

Replacing fish with beef was found to be the most costly; to replace the fish harvest in the LMRB estimated to be lost due to dam construction with beef would require 3.6% of the total discharge of the Mekong River, which is equivalent to a 28% increase in water withdrawal compared to current levels.

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To replace all of the fish harvested in the LMRB with beef would require an additional 395,048 km^2 of land (equivalent to 65% of the total area of the Mekong River basin) and a 63% increase in water withdrawal. Replacing the fish with chicken would require the least additional land and water but still would require more than 36,000 km^2 of land and an 8% increase in total water withdrawal from the Mekong River.

The replacement analysis for the fish consumed in the four countries demonstrates that Cambodia would have the highest requirements in terms of increased use of land and water followed by Thailand and Vietnam, whereas Laos have lower requirements but would still need to increase its land use significantly.

Overall, our analysis shows that freshwater fish is a highly valuable source of animal protein and micronutrients in LMRB. Replacing the fish protein with other sources of animal protein will require a substantially higher use of land and water.

Introduction

Freshwater capture fisheries in the lower Mekong River basin (i.e., Cambodia, Laos, Thailand and Vietnam) are reported to be between 2.0 and 2.6 million metric tons (van Zalinge et al. 2004; Hortle 2007; ICEM 2010; MRC 2014), which is probably an underestimation of actual catch (Hortle and Bamrungrach 2015; IFREDI 2013; Lymer et al. 2008; Coates 2002). This makes it the largest connected freshwater fishery in the world and corresponds to between 17% and 22% of total official global inland capture fisheries catch (FAO 2014c). In the countries of the lower Mekong basin, freshwater fish are a crucially important source of nutrition, with Cambodia and Laos having among the highest fish protein consumption of nonisland states (FAO 2014b; FAO 2014d; Hall et al. 2013). These fish and fish products are often culturally preferred and easily accessed by the poor (Belton and Thilsted 2014).

There are currently 11 proposed dam construction projects in the lower Mekong basin (ICEM 2010; Orr et al. 2012) that will have significant effects on the quality and quantity of harvestable resources from inland fisheries (WorldFish 2013). Increasing human population and demand for energy are driving these projects. It is estimated that only 5% of the potential hydroelectric power in the Mekong basin is currently exploited; this 5% has an economic value of US$235 million per year (MRC 2005). However, it has been estimated that a large part of the fish harvest in the Mekong River and the associated nutritional and social benefits will be lost due to dam construction (Ziv et al. 2012; Dugan et al. 2010). Baran (2010) estimated that freshwater capture fisheries in the lower Mekong River basin could decline by 880,000 metric tons in 2030 if dam construction proceeds as planned.

If there was a decline in freshwater capture fisheries due to dam construction, fish protein would have to be replaced by another source to maintain current consumption levels and meet the nutritional requirements of the human population. Livestock production is the other important source of protein in the countries of the lower Mekong basin (FAO 2014b), and in 2011, the average daily per capita consumption of protein for these countries combined was 4.9 g for freshwater fish and 9.6 g for bovine, pig, and poultry meat (Table 1).

Freshwater fish is a crucial source of protein for the most poor and vulnerable people because it requires much lower investments compared to livestock production and it is estimated that about 1×10^9 people worldwide rely on fish as their primary source of animal protein (FAO 2000). The rapid population

Table 1.—Daily per capita protein consumption by protein source in the lower Mekong River basin in 2011 (FAO 2014b).

	Freshwater fish (g/d)	Bovine, pig, and poultry meat (g/d)
Cambodia	9	5
Laos	4.8	6.3
Thailand	2.3	9
Vietnam	3.5	17.9
Mean	4.9	9.6

growth, urbanization, and increase in the per-capita income in the Mekong region will lead to a higher demand for animal products; the demand for meat is expected to increase by more than 140% between 2005 and 2050 in East Asia (China excluded) (Alexandratos and Bruinsma 2012).

While freshwater capture fisheries have a negligible footprint on land and water, livestock is an important user of these resources and can compete with other sectors for land (e.g., industry, housing, and crop production). On a global scale, livestock production uses about 30% of the global ice-free land (25% through grazed land and 5% through feed crops; Monfreda et al. 2008; Ramankutty et al. 2008) and 29% of the total agricultural water (Mekonnen and Hoekstra 2012). The replacement of freshwater fish protein by livestock protein would, therefore, be accompanied by environmental costs.

The objective of this study was to assess the environmental cost in terms of land and water use if freshwater fish proteins were replaced by livestock proteins in the four countries of the lower Mekong River basin.

Method

Nutrition components and requirements

To determine the contribution of freshwater fish to protein, calcium, iron, zinc, and vitamin A to the nutritional requirements of the four countries (Thailand, Vietnam, Laos, and Cambodia) in the lower Mekong River basin, we calculated the mean freshwater fish composition (FC) from the literature. To establish the nutrient requirements of the population in the lower Mekong River basin, the population of the four countries was separated by country and by gender into 22 age categories spanning 5-year intervals (UN 2014). Each age category was multiplied with the nutrient requirements for that age and gender category, for protein (WHO 2002), calcium, iron, zinc, and vitamin A (WHO and FAO 2004). The estimated freshwater fish consumption per country (FishC) was calculated from fish consumption data from the four countries (Needham and Funge-Smith 2014) and human population (UN 2014) as follows:

$$\begin{aligned}\text{FishC}_{\text{country } x} &= \left(\text{Per capita fish consumption}_{\text{country } x}\right) \\ &\times \left(\%\text{ freshwater fish consumed}_{\text{country } x}\right) \\ &\times \left(\text{Population}_{\text{country } x}\right)\end{aligned} \tag{1}$$

The contribution of the fish consumed to the four countries' nutrient requirements (CFFnutrient) was calculated using mean freshwater fish composition for small freshwater fish (SSF), large freshwater fish (LFF), or average of SFF and LFF, as follows:

$$\begin{aligned}\text{CFF}_{\text{nutrient}} &= \text{sum}\left(\text{NR}_{\text{countries}}\right)/\text{sum}\left(\text{FishC}_{\text{countries}}\right) \\ &\times \text{FC}_{\text{nutrient}}\end{aligned} \tag{2}$$

where

$\text{CFF}_{\text{nutrient}}$ = contribution of freshwater fish to nutrient requirements of the total populations (by gender) in countries (nutrients = protein, calcium, iron, zinc, and vitamin A)

$\text{NR}_{\text{country}}$ = nutrient requirements per country (country = Cambodia, Laos, Vietnam, Thailand)

$\text{FishC}_{\text{country}}$ = freshwater fish consumption per country (country = Cambodia, Laos, Vietnam, Thailand)

$\text{FC}_{\text{nutrient}}$ = mean freshwater fish composition (nutrients = protein, calcium, iron, zinc, and vitamin A)

Replacement scenarios

To estimate the land and water requirements to replace freshwater fish with livestock protein sources in the region, three different scenarios were used: (1) the replacement quantity of proteins for the total harvest of freshwater fish (FishH) in the Mekong River basin freshwater fish was calculated based on a 2 million metric tons estimated total harvest of freshwater fish (MRC 2014), (2) the replacement quantity of proteins for the freshwater fish consumption (FishC) of the four countries in the lower Mekong River basin, and (3) the replacement quantity of proteins for the potential loss of Mekong River basin harvested fish (FishL) from dam construction estimated to be 880,000 metric tons (Baran 2010). For the three scenarios, FishH, FishC, and FishL, the average protein content of freshwater species ($FC_{protein}$) was used to convert fish weight to grams of protein.

Livestock data: production, land, and water requirements

Livestock data for four alternative protein sources (beef, chicken [including meat and eggs], pork, and milk [from cows]) were obtained from the Global Livestock Environmental Assessment Model (GLEAM; Gerber et al. 2013; MacLeod et al. 2013; Opio et al. 2013). GLEAM is georeferenced; therefore, all data can be spatially disaggregated at region, country, or intracountry level. Data can also be disaggregated by species, commodities, and production system.

Production (kilograms of protein) and land use (km^2) for the four alternative protein sources were extracted from GLEAM by country and by protein source. Land use was derived from the quantity of feed consumed by livestock. The ratio between land use and production was computed to obtain the land use requirements of 1 kg of protein for the four alternative protein sources. Water requirements were obtained from Mekonnen and Hoekstra (2012).

Land and water requirements for protein replacement

For the total fish harvest (FishH) and fish harvest lost (FishL) to dam construction , the Mekong River basin fish protein environmental replacement quantity for the four alternative protein sources, in terms of land (GLEAM model) and water (Mekonnen and Hoekstra 2012), was calculated as follows:

$$\begin{aligned} &\text{Basin replacement quantity land}_{\text{protein source}} \\ &\quad = \left(\text{Land requirement}_{\text{protein source region average}}\right) \\ &\quad \times \left(\text{Fish protein [kg]}\right) \end{aligned} \tag{3}$$

$$\begin{aligned} &\text{Basin replacement quantity water}_{\text{protein source}} \\ &\quad = \left(\text{Water footprint}_{\text{protein source}}\right) \\ &\quad \times \left(\text{Fish protein [kg]}\right) \end{aligned} \tag{4}$$

The Mekong River basin equivalents (MRBeq) per alternative protein source were calculated by dividing the respective Basin replacement quantity $\text{land}_{\text{protein source}}$ with the total Mekong River basin area (795,000 km^2; FAO 2014a). The change in land use (↑Land use) was calculated by dividing Basin replacement quantity $\text{land}_{\text{protein source}}$ by the current total land use. Basin replacement quantity $\text{water}_{\text{protein source}}$ was divided by water withdrawal (62 km^3; FAO 2014a) or total discharge of the Mekong River into the South China Sea (475 km^3; FAO 2014a) and presented as change in water withdrawal compared to current level (↑WW) and fraction of total discharge of Mekong River (TDMR).

For freshwater fish consumption per country (FishC), the country fish protein environmental replacement quantity (i.e., land and water quantity) per alternative protein source is calculated as follows:

$$\begin{aligned} &\text{Country replacement quality land}_{\text{protein source country}} \\ &\quad = \text{Land requirement}_{\text{protein source country}} \\ &\quad \times \text{Fish protein (kg)}_{\text{country}} \end{aligned} \tag{5}$$

$$\begin{aligned} &\text{Country replacement quality water}_{\text{protein source country}} \\ &\quad = \text{Water footprint}_{\text{protein source}} \\ &\quad \times \text{Fish protein (kg)}_{\text{country}} \end{aligned} \tag{6}$$

Fish protein environmental replacement quantities in country area equivalents (Country eq.) per alternative protein source and country was calculated by dividing the respective Country replacement quantity $\text{land}_{\text{protein source}}$ with the total country area (Laos 236,800 km^2; Thailand 513,120 km^2; Cambodia 181,035 km^2; Vietnam 331,210 km^2; FAO 2014a). The change in land use (↑Land use) was calculated by dividing Country replacement quantity $\text{land}_{\text{protein source}}$ with the current total country land use. The Country replacement quantity $\text{water}_{\text{protein source}}$ was divided by total country water withdrawal (Laos 3.96 km^3/year; Thailand 57.30 km^3/year; Cambodia 2.18 km^3/year; Vietnam 82.03 km^3/year; FAO 2014a) and presented as change in water withdrawal compared to current level (↑WW).

Results

The estimated freshwater fish composition (FC) highlights that small freshwater fish species (SFF) have a much higher mean composition of all the minerals (759.13 mg Ca, 9.70 mg Fe, and 5.65 mg Zn) and vitamin A, whereas the large freshwater fish species (LFF) have higher mean protein content (18.49 g; Table 2).

The total consumption of freshwater fish per country (FishC) across the four countries is highest in Thailand (750,373 metric tons), followed by Cambodia, Vietnam, and Laos (Table 3).

The sum of the four countries' nutrient requirements (Sum [NRCambodia, NRLaos, NRVietnam, NRThailand]) of the population in the lower Mekong River basin show that a total of 3 million metric tons of protein is needed each year and that the female human population needs relatively more iron than the male population (Table 4)

The contribution of the freshwater fish consumed to human nutrition in the four countries in the lower Mekong River basin was significant (>10%) for all the assessed nutrient components (Table 5) and especially for small freshwater species that contribute greatly to vitamin A (73%) and zinc (49%) requirements. Freshwater fish protein contributes between 11% and 12% of total protein requirements of the human population.

Freshwater fish consumption per country (FishC) is 33% of the total of the five assessed animal protein sources produced in the four countries (356,005 metric tons of fish consumed divided by 1,063,153 metric tons of fish, chicken, pig, beef, and milk; Table 6). Fish protein production (FishH) in the four countries is extremely high and second only to pig protein production (Table 6). Fish protein loss due to dam construction (FishL) was also high and greater than protein production from beef and milk (Table 6).

Currently, beef and pig production have the highest land uses in the four countries, but chicken production also has high land use in Thailand (Figure 1).

The average land requirements were highest for beef (1.130 m^2/g protein) followed by milk, pig, and chicken; the global average water requirements was also highest for beef (112 L

Table 2.—Protein and micronutrient composition per 100 g of freshwater fish. Analysis divided into small freshwater fish (SSF; Roos 2001; Roos et al 2007a, 2007b, 2007c; Mazumder et al 2008; Karapangiotidis et al. 2010) and large freshwater fish (LFF; Roos et al 2007a; Karapangiotidis et al. 2010; USDA 2011) and the average of all the fish species in the two groups (AFF). RAE = retinol activity equivalent. n.d. = no data.

	Protein g	Total lipid g	Calcium mg	Iron mg	Zinc mg	Vitamin A ug RAE	B12 ug
SFF	16.48	2.51	759.13	9.70	5.65	1,272.50	n.d.
LFF	18.49	4.16	310.00	5.03	1.59	163.25	2.30
AFF	17.48	3.29	521.35	7.23	3.50	717.88	2.30

Table 3.—The estimated freshwater fish consumption (FishC) in the countries in the lower Mekong River basin.

	FishC (metric tons)
Laos	122,158
Thailand	750,373
Cambodia	644,073
Vietnam	520,037
Total	2,036,641

Table 4.—The calculated yearly nutrient requirements for selected micronutrients of the human population in the four countries in the lower Mekong River basin.

	Protein (metric tons)	Calcium (metric tons)	Iron (metric tons)	Zinc (metric tons)	Vitamin A (metric tons)
Male	1,519,193	31,472	274	128	18
Female	1,557,644	34,197	452	103	17
Total requirements	3,076,837	65,669	726	232	35

Table 5.—The calculated contribution of the freshwater fish consumed to human nutritional requirement for the population of the four countries in the lower Mekong River basin.

	Protein (%)	Calcium (%)	Iron (%)	Zinc (%)	Vitamin A (%)
Small freshwater fish species	10.9	23.1	26.7	48.8	72.8
Large freshwater fish species	12.2	9.4	13.9	13.8	9.3
Average freshwater fish species	11.6	15.9	19.9	30.3	41.1

Table 6.—The determined protein quantity from the four alternative protein sources and the three fish scenarios in the four Mekong River basin countries. FishH represents total fish harvest, FishC represents freshwater fish consumption, and FishL represents fish lost to dam construction in the Mekong River basin. mt = metric tons.

Country	Chicken (mt)	Pig (mt)	Beef (mt)	Milk (mt)	FishH (mt)	FishC (mt)	FishL (mt)
Cambodia	5,034	8,522	8,525	1,543		112,584	
Laos	4,083	434	4,455	490		21,353	
Thailand	149,097	120,422	17,974	19,892		131,165	
Vietnam	91,167	256,212	18,736	6,967		90,902	
Total	249,381	385,590	49,690	28,892	349,600	356,005	153,824

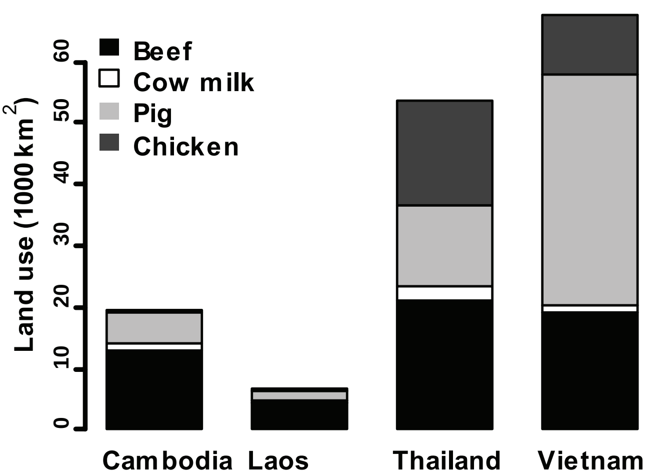

Figure 1.—Current land use for the four alternative protein sources in the four countries in the lower Mekong River basin.

per gram protein) and lowest for chicken (Table 7).

To replace the fish harvested (FishH) in the Mekong River basin with beef would require 395,048 km^2 of land, which is equivalent to 65% of the area of the total Mekong River basin (Table 8) and would require 8% of the total discharge of the Mekong River, which is equivalent to a 63% increase in water withdrawal compared to current levels (Table 9). Increasing production with the current shares of alternative protein sources (current mix, Table 9) in the region would result in an increased land requirement of 64,739 km^2 and 18 km^3 of water.

The replacement requirements for the fish harvest estimated to be lost (FishL) due to dam constructions in the Mekong River basin with beef would be 173,821 km^2, which is equivalent to 28.7% of the area of the total Mekong River basin (Table 8). Further, replacing the loss of fish harvest (FishL) with beef would require 3.6% of the total discharge of the Mekong River, which is equivalent to a 28% increase in water withdrawal compared to current levels (Table 9). Increasing production with the current shares of alternative protein sources produced in the region (current mix) would result in an area requirement of 28,485 km^2 and 8 km^3 of water.

To replace the freshwater fish consumed per country (FishC) within the countries in the Mekong River basin with beef would require 165,048 km^2 more land in Cambodia, equivalent to 91.2% of the country's area; 152,545 km^2 of land in Thailand, equivalent to 29.7% of the country's area; 93,902 km^2 of land in Vietnam, equivalent to 28.4% of the country's area; and 21,396 km^2 of land in Laos, equivalent to 9.0% of the country's area, (Table 10; Figure 2). It would also require an increase in water use compared to current levels of 577%

Table 7.—The estimated land requirement (m^2/g protein) and water requirement (L/g protein) for production of four protein sources in the Mekong River basin countries. Average land requirements for the protein sources are weighted by the country areas.

	Land requirement (m^2/g protein)					Water footprint (L/g protein)
Food product	Cambodia	Laos	Thailand	Vietnam	Average	Global average
Chicken	0.122	0.090	0.107	0.091	0.104	31.5
Pig	0.116	0.103	0.107	0.100	0.105	57.0
Beef	1.466	1.002	1.163	1.033	1.130	112.0
Milk	0.918	0.620	0.122	0.159	0.331	31.0

Table 8.—The requirements (increase in land use) of replacing the fish produced in the Mekong River basin (FishH) and the estimated loss due to dam construction (FishL) with alternative protein sources. Data presented per alternative protein source or using the current mix of production of the four assessed alternative protein sources (current mix), computed with land requirements from Table 3, and the required land area as Mekong River basin equivalents (MRB eq.) and the increased land use compared to current levels (↑Land use), both expressed as percentages.

	Basin replacement quantity land (km^2)		MRB eq. (%)		↑Land use (%)	
	FishH	FishL	FishH	FishL	FishH	FishL
Chicken	36,358	15,998	6.0%	2.6%	24.6%	10.8%
Pig	36,708	16,152	6.1%	2.7%	24.8%	10.9%
Beef	395,048	173,821	65.2%	28.7%	266.9%	117.4%
Milk	115,718	50,916	19.1%	8.4%	78.2%	34.4%
Current mix	64,739	28,485	10.7%	4.7%	43.7%	19.2%

Table 9.—The requirements (increase in water use) from replacing fish harvested in the lower Mekong River basin (FishH) and the estimated loss due to dam construction (FishL) with alternative protein sources. Data presented per alternative protein source or using the current mix of production of the four assessed protein sources (current mix) and as increase in water withdrawal compared to current level (↑WW), and percentage of total discharge of Mekong river (TDMR).

	Basin replacement quantity water (km^3)		TMDR (%)		↑WW (%)	
	FishH	FishL	FishH	FishL	FishH	FishL
Beef	39	17	8.2%	3.6%	63%	28%
Pig	20	9	4.2%	1.8%	32%	14%
Chicken	11	5	2.3%	1.0%	18%	8%
Milk	11	5	2.3%	1.0%	17%	8%
Current mix	18	8	3.7%	1.6%	29%	13%

in Cambodia, 25.6% in Thailand, 12.4% in Vietnam and 60.4% in Laos (Figure 2). The replacement requirement for the fish consumed in the four assessed countries show that Cambodia would have the highest relative requirements in terms of land and water followed by Thailand and Vietnam, whereas Laos would have lower requirements but would still need to increase its land use significantly (Figure 2).

Discussion

This paper presents a preliminary analysis illustrating that freshwater fish contribute significantly to protein and micronutrient re-

Table 10.—The replacement quantity for land and water to replace the freshwater fish consumed (FishC) in the four countries in the lower Mekong River basin, per protein source.

		Country replacement quantity land (km^2)	Country replacement quantity water (km^3)
Cambodia	Beef	165,048	12.61
	Pig	13,060	6.42
	Chicken	13,735	3.55
	Milk	103,352	3.49
	Current mix	73,948	7.91
Laos	Beef	21,396	2.39
	Pig	2,199	1.22
	Chicken	1,922	0.67
	Milk	13,239	0.66
	Current mix	11,690	1.53
Thailand	Beef	152,545	14.69
	Pig	14,035	7.48
	Chicken	14,035	4.13
	Milk	16,002	4.07
	Current mix	22,261	6.21
Vietnam	Beef	93,902	10.18
	Pig	9,090	5.18
	Chicken	8,272	2.86
	Milk	14,453	2.82
	Current mix	13,250	4.88

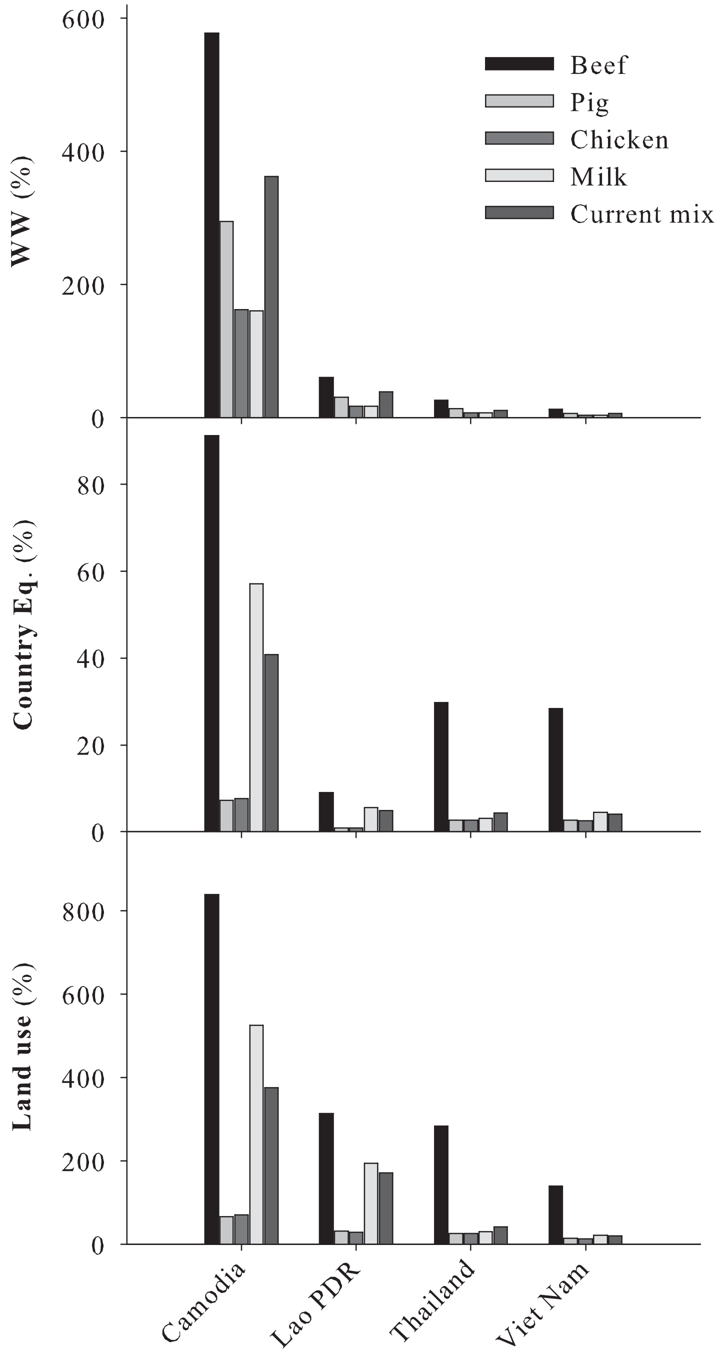

Figure 2.—The requirements, increase in water and land use, of replacing the fish consumed per country (FishC) in the countries in the lower Mekong River basin. The increases are presented as change in water withdrawal compared to current level (WW), the land requirement in country area equivalents (Country eq.), and change in land use compared to current levels of land use (Land use).

quirements in the lower Mekong River basin. This contribution is similar throughout the developing world. Developing countries produce more than 95% of total inland fish harvest, with much of that production being locally consumed (FAO 2010).

Replacing fish as a protein source with other animal protein sources would require allocation of additional land and water resources, with some countries needing to allocate more due to their higher reliance on fish for protein. The loss in fish harvest due to the proposed dam construction in the Mekong River main stream will incur severe requirements in terms of land and water to replace the fish protein (Figure 3). Our analysis show higher replacement requirements than previous estimates (Orr et al. 2012); for example, the land requirement we calculated (current mix) is 402% (minimum) to 117% (maximum) of Orr et al.'s (2012) assessment. These additional resource requirements may however be reduced through technological advances and improved resource-use efficiency. Land and water use per protein source for the assessed protein sources in the four countries differs substantially from those in OECD (Organisation for Economic Co-operation and Development) countries (Figure 4).

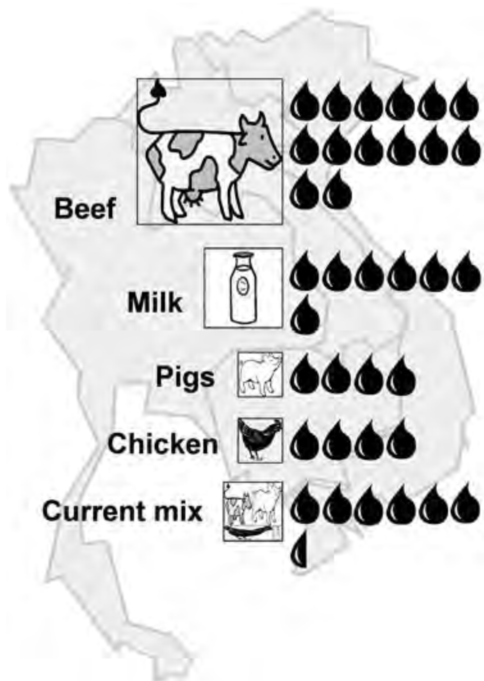

Figure 3.—The requirements (increase in land and water use) of replacing the estimated loss of fish harvest due to dam construction, by alternative livestock protein sources. Land requirements are represented as squares whose areas are scaled to the background map of the countries surrounding the lower Mekong River basin. Water requirements are represented as drops, each drop representing a 2% increase compared to current use. See Tables 8 and 9 for values.

In understanding the replacement requirements for the fish harvested and consumed and potentially lost, one needs to consider how the additional quantity of protein from local production of terrestrial animals will be met. Replacing fish protein with livestock protein can be met in different ways (e.g., increasing the number of livestock, which will demand more resources in terms of land and water resources; improving animal productivity, which will demand more water [surface and groundwater], or increasing imports of animal protein, which will result in lower additional land requirements. Land and water resources are however not the only constraints or environmental impacts to consider when replacing aquatic protein with terrestrial protein. Changes in food production patterns have important implications for greenhouse gas (GHG) emissions and carbon, nitrogen, and phosphorus cycles. Livestock have an important contribution to GHG emissions in East Asia (more than 1×10^9 metric tons CO_2 equivalent; Gerber et al. 2013), whereas GHG emissions from inland fisheries can be assumed to be negligible as fishing practices within the region are mostly traditional, based on manual labor and limited use of motorized boats (Welcomme et al. 2016). Regarding land use, emission intensities from livestock largely vary among species and commodities, and the level of productivity and types of practices also have a huge effect (Gerber et al. 2013; Pierrehumbert and Eshel 2015). Replacement requirements in terms of GHG emissions would, thus, differ significantly according to the livestock commodity used as a replacement and changes in current produc-

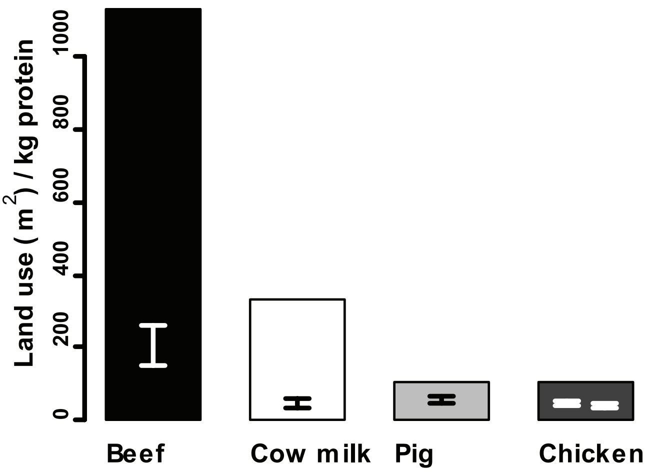

Figure 4.—Average land use of four protein sources in the four Mekong River basin countries (bars: GLEAM [global epidemic and mobility model], with the average land use for OECD (Organisation for Economic Co-operation and Development) countries (for chicken, ranges for meat [left] and eggs [right] are shown) as black ranges (de Vries and de Boer 2010).

tivity and practices, but also would depend on changes in the aquatic environment (Barros et al. 2011; Raymond et al. 2013).

Further, there will be effects on biodiversity and human health (Goedkoop et al. 2012). This effect will vary depending on land uses because different land uses (e.g., grazing on grassland versus intensive cropland) do not have the same effect on biodiversity. The effect of water use on biodiversity and human health also will vary with the level of water scarcity. Methods could be used to translate the land and water use for livestock into impacts on biodiversity and human health (e.g., Alkemade et al. 2009; Pfister et al. 2009; de Baan et al. 2013), whereas no comparable methods exists to compute the impact of freshwater fisheries.

In addition to the increased land and water use to replace the loss of fish harvest, there will also be losses of other nutritional components that will not be replaceable by production of livestock, for example, vitamin A. Micronutrient deficiency significantly affects the lives and health of around 2×10^9 people worldwide (Tulchinsky 2010), with 26% of all children under the age of 5 being stunted and 31% suffering from vitamin A deficiency (FAO 2013). Fish contain several amino acids essential for human health and a unique lipid composition with many potential beneficial effects for adult health and child development and is an important source of essential micronutrients (vitamins D, A, and B) and minerals (calcium, phosphorus, iodine, zinc, iron, and selenium); this is especially true for many small fish species that are consumed (Kawarazuka and Béné 2011; HLPE 2014). Clearly, the fish consumed in the region contribute significantly to nutritional requirements for calcium, iron, zinc, and vitamin A, in addition to protein (Table 4), and contributes significantly to the nutrient requirement for women (Chamnan et al. 2009). Replacing these nutrients from fish with livestock would require even more land and water than simply replacing the protein.

The decisions leading to the construction of dams on the Mekong were based on the value of electricity and water for agriculture and municipal use. The value of inland fishery resources and the cost of replacing them, in terms of both land and water, were not adequately considered in our opinion. We do hope however, that with improved knowledge on the importance of freshwater fish, more informed decisions can be taken in countries in the lower Mekong River basin and elsewhere.

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Drivers and Synergies in the Management of Inland Fisheries: Searching for Sustainable Solutions

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Abstract.—Water availability is driven by external forces, including climate change and human population growth. Inland fisheries are one of many social and economically important sectors that utilize inland waters. Increasingly, the competition for water leads to tough decisions and trade-offs are often made between water resource sectors. However, decisions that consider multiple sectors can lead to synergies in management approaches (i.e., win–win scenarios), which benefit multiple sectors. Ultimately, in searching for sustainable solutions for fish, these ecologically and socially responsible approaches can contribute to improved health, well-being, and prosperity for all water resource sectors.

Introduction

Less than 3% of the world's supply of water is fresh (Stiassny 1996). Yet freshwater is home to more than 40% of known fish species (Kummu et al. 2011). Not surprisingly, this small fraction of water provides a large range of economically, culturally, and ecologically valuable services to many important sectors. Increasingly, the competition for water leads to tough decisions, and trade-offs are often made between these sectors.

Inland capture fisheries from lakes, rivers, streams, canals, reservoirs, and other landlocked waters for food, income, or recreation (FAO 2014a) is one important sector that relies upon water of suitable quality and quantity. Inland fish provide a major source of protein, essential fats, and micronutrients for hundreds of millions of people globally (Youn et al. 2014). In low income countries, inland fisheries provide livelihoods for more than 60 million people and women represent more than half of those in inland fisheries supply chains (FAO 2014b). Inland fish and fisheries also provide cultural and recreational services and contributions to human health and well-being (Lynch et al. 2016).

Though inland fish and fisheries are important in providing food security, human well-being, and ecosystem productivity, inland fisheries are often underappreciated or not considered during water resource planning (Lynch et al. 2016). Valuation of inland fisheries is difficult and the governance structures for water are often complex, unclear, or nonexistent, assuring that the direct comparisons of economic values are often not possible (see Bartley et al. 2016; Youn et al. 2016; both this volume). Additionally, inland fisheries are an economically small sector, and in most cases, their value will not be the main driver of capital or resource-based decision making.

This chapter examines the sectors that compete most directly with inland fisheries for water resources and discusses the global drivers that also influence water quantity and quality (Figure 1). Using a series of case studies (Figure 2) to illustrate real world examples of these issues, the chapter highlights synergies in management approaches (i.e., win–win scenarios) and provides recommendations to achieve a sustainable future for fish, fisheries, and other inland sectors (Table 1). Informed management decisions that consider the potential impacts of all sectors on inland water systems can allow for the development of aquatic habitat rehabilitation and protection programs, environmental flow regimes, or other management approaches for sustainable production of ecosystem services across multiple sectors. Ecologically and socially sustainable approaches ultimately can contribute to improved human and environmental health, well-being, and prosperity of all water resource sectors, including fisheries-dependent communities.

Competing Inland Water Sectors

While fishing itself is often the largest human influence on marine fisheries, inland fish and fish-

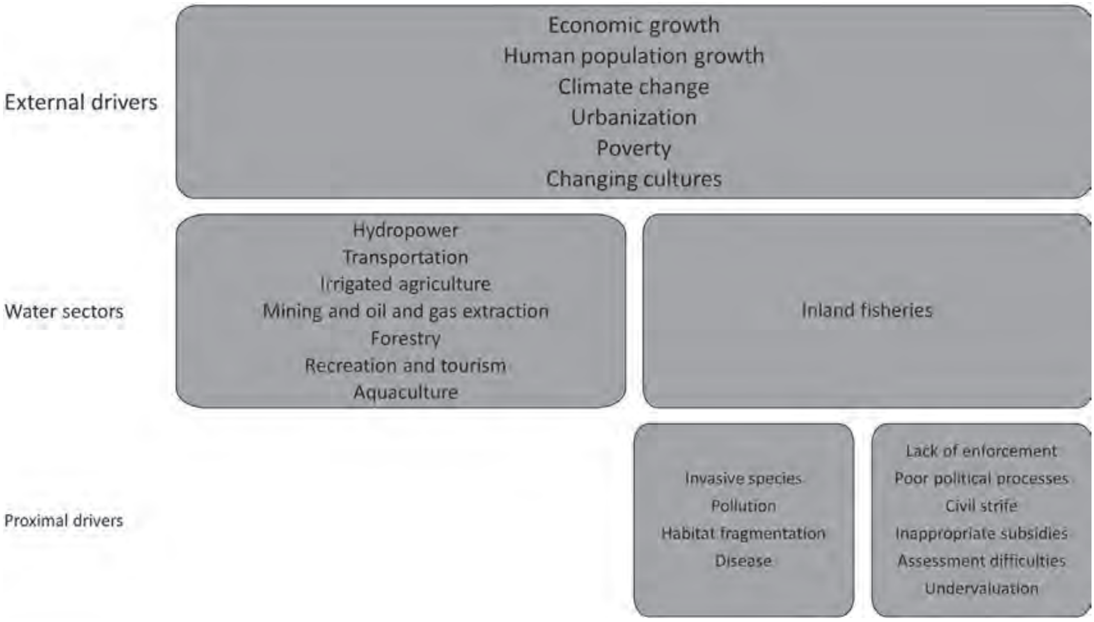

Figure 1.—Drivers of inland water sectors with a focus on inland fisheries.

eries are dependent upon the quantity and quality of freshwater habitats, which are influenced primarily by external factors. Many sectors competing with inland capture fisheries (e.g., hydropower, transportation, agriculture, mining, oil and gas extraction, forestry, aquaculture, tourism, and recreation) influence management and allocation decisions for inland water systems, often to the detriment of sustainable inland fisheries. Identifying competing sectors should allow more informed discussions about management of inland systems.

Habitat modification

Hydropower uses water to produce renewable energy. An estimated 8,600 dams higher than

Figure 2.—Case study locations: (1) Rewa Village, (2) Lake Cyohoha, (3) Rupa Lake, (4) Wuhu Lake, and (5) Mekong Delta.

Table 1.—Recommendations from Drivers and Synergies Working Group[a].

Concern/issue	Recommendation	Examples
Inland fisheries are not often considered in decisions about allocation of water partially because they are not generally compared in economic terms to other sectors. In many cases, especially in the developing world, markets do not exist or economic impact is not measured for inland fish and fisheries.	Develop market or other other economic evaluation approaches to communicate the importance and the true value (including illegal, unreported, or unregulated) of inland fish and fisheries supply chain to other sectors, particularly for consideration in water allocation discussions.	• The lower Mekong Delta fishery has been assessed for its economic as well as its biological, cultural, and social value (Baran et al. 2007). • A reflooding scheme was required to reverse impacts on fishery and nonfishery sectors not initially accounted for during the construction of the Maga Dam, Cameroon (Loth 2004). • See Youn et al. 2016, this volume, for further examples.
Development of goals around common needs such as production of clean water can sometimes lead to win–win approaches across water resource sectors. In many instances, however, trade-offs between sectors and ecosystem services from inland water systems will be made.	Although there may be some win–win situations, explicitly acknowledge the trade-offs made when allocating water.	• A synergy between fishery and tourism sectors to create a new, economically productive sector in Guyana (see Rewa Village case study) and aquaculture with agriculture farming systems (FAO 2001) are examples of win–win solutions. • Adoption of alternative aquaculture species and practices as a trade-off to reduce impacts on environmental quality (see Mekong Delta and Wuhu Lake case studies).
Inland fish and fisheries share water systems with other water resource sectors. Planning mechanisms often do not explicitly include inland fish and fisheries.	Develop integrated cross-sectoral approaches to managing water systems for all fishery and and nonfishery sectors.	• The European Water Framework Directive (2000/60/EC; European Parliament 2000) and the Lake Cyohoha community (see Lake Cyohoha case study) require integrated water management to protect, among others, fish and ecological health at the river basin scale. • See Bartley et al. 2016, this volume for further examples.
Inadequate communication among sectors, stakeholders, and partners because of a lack of common governance structures and differences in objectives and language.	Use participatory approaches to better align goals for water management across sectors.	• Mekong Integrated Water Resources Management Project integrates fishery development along other water-use sectors (Browder 2014) and transboundary projects like GEO Amazonia (UNEP 2008) foster communication. • Use of cooperative management approaches to restore ecological function and economically profitable fisheries (see Lake Rupa case study)

Table 1.—Continued.

Concern/issue	Recommendation	Examples
Inland fish do not appear in the global discussion of water use.	Incorporate inland fish and fisheries into the United Nations Economic and Social Council post-2015 development agenda and other sustainability development goals on water issues.	• In the post-2015 development agenda, inland fisheries are directly relevant for at least four sustainable development goals (SDGs): no poverty (SDG1), no hunger (SDG2), gender equality (SDG5), and life on land (SDG15).

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15 m are in operation globally for hydropower generation (Zarfl et al. 2014). In 2011, hydropower contributed approximately 16% of total global electricity in more than 160 countries (Moller 2012). Brazil, Canada, China, and the United States produce more than half of the world's hydropower. The World Business Council for estimates that two-thirds of the economic potential of hydropower remains unexploited, mostly in the developing world, and the International Energy Agency projects that hydropower capacity will increase by 63% between 2002 and 2030 (WBCSD 2006). While dams and hydropower plants are a renewable source of energy, hydropower generation can be in conflict with other water resource users, including inland fisheries.

Nearly 50% of the world's highest flow rivers have been modified by dams and other obstructions to create upstream reservoirs (Lehner et al. 2011). The resulting habitat modifications have led nearly 65% of the world's continental discharge (measured at the mouth of ocean-flowing rivers) to be classified as threatened (Vörösmarty et al. 2010). Dams (Note that not all dams function for power development; some are built to provide transportation corridors or water storage. However, the vast majority of large dams are built for power generation.) have impacted more than half of the world's largest rivers, including the most biologically diverse systems, such as the Amazon, Columbia, Mekong, Mississippi, and Nile (Nilsson et al. 2005), with particularly negative effects on endemic species. The construction of dams has also resulted in long-term storage of carbon in reservoirs and a reduction in the overall delivery of sediment to coastal zones (Syvitski et al. 2005), thereby reducing primary production and the development of deltas and other habitat important for inland fish production.

Progressive hydropower planning includes biologically appropriate mitigation strategies (e.g., fish ladders, variable flow regimes) to minimize ecological impacts on fish while still meeting electricity demands for people. If these factors are not taken into consideration, dams will disrupt fish reproduction by blocking migration routes, both downstream and upstream, and fragmenting habitat. Reservoirs displace many people who depend on the natural run of rivers for their livelihoods. Replacement fisheries in reservoirs, oftentimes aquaculture, have investment costs that often cannot be borne by displaced fishermen. In addition, aquaculture species may not be culturally or socially acceptable (WWAP 2014), and aquaculture is generally unable to produce all the species that are lost. For example, hydropower dams on the Mekong main stem are estimated to cause losses of US$476 million per year for fisheries alone (Orr et al. 2012), and tributary dams will have strong nonlinear trade-offs with floodplain fisheries (Ziv et al. 2012). With committed restoration and management efforts, such as on the Columbia River in the United States, technological mitigation may save fish stocks from local extinction, but there is yet to be evidence that they can provide complete mitigation for the altered ecosystems (Williams 2008).

Inland waterways have been significantly modified over the centuries to provide transportation corridors for commerce and the movement of people. Modern economies would not have been possible in the absence of transportation on inland waters (INA 2003). Modifications of inland waterways for transportation include the construction of locks and dams, channelization, and alteration of riparian corridors. Channelization increases the potential for habitat modification. Once modified, inland water systems often experience changes in sediment transport, water quality, fragmentation and loss of habitat, and shifts in hydrological regimes. Learning from past failings, many transportation planning efforts now include mandates to consider the environmental consequences (e.g., environmental impact statements). For example, lock systems developed in a side canal can accommodate continuous flow in a river system.

Additionally, extensive modification of inland water systems to affect connectivity between drainages has often created corridors for invasive species with associated undesirable impacts (Revenga et al. 2000; Revenga and Kura 2003). The construction of the Welland Canal, for example, provided a commercial transportation route between Lake Ontario and Lake Erie. The introduction and spread of many invasive species, including Sea Lamprey *Petromyzon marinus*, has been attributed to this transportation channel (Eshenroder 2014). Commercial and recreational fishing and tourism businesses in the Laurentian Great Lakes are believed to lose up to $50 million annually from nonnative Sea Lamprey and mollusks brought through the creation of these transportation corridors (Rosaen et al. 2012). Similarly, release of ballast water has been cited as a transport vector for many invasive species (e.g., Ricciardi and MacIsaac 2000).

Water quality and quantity

Production of traditional agricultural products consistently places a large demand on limited freshwater resources (FAO 2014c). Agriculture produces both crops and livestock through processes that result in impacts to terrestrial and aquatic ecosystems. Irrigated agriculture, alone, uses 69% of global freshwater withdrawals (Chen and Davis 2014). With increasing food demand globally, agricultural intensification will require more water for irrigation (FAO 2014c). During the past 35 years, food production from agriculture has doubled, nitrogen fertilization has increased more than sixfold, and the use of phosphorus for fertilization has increased more than threefold, resulting in degradation of water quality and increases in eutrophication (Tilman 1999; see Lake Rupa case study). Similarly, animal production facilities have destroyed shoreline habitat (e.g., unfenced grazing) and significantly increased nutrient loads in local watersheds (e.g., concentrated animal feeding operations). In that same time, there have been collective efforts to increase awareness and address ecological water needs. Even voluntary adjustments to irrigation practices can have significant benefits to fish habitat.

Agricultural impacts when unchecked, including dewatering and eutrophication, threaten inland fish with loss of biodiversity, shifts in food webs, spread of invasive species, and large-scale changes to fisheries (Tilman 1999; see Lake Cyohoha case study). Increased nutrient loading, for example, altered fish community composition in Ohio stream systems, decreasing the relative abundance of top aquatic carnivores and insectivores and increasing the relative abundance of nutrient tolerant and omnivorous fishes (Miltner and Rankin 1998). More directly, fish can be diverted from rivers into irrigation canals and even dispersed onto crops during watering events (King and O'Connor 2007). However, technological advances, such as fish screens, have increasingly been implemented to address these large-scale ecological impacts with minimal implementation costs, potentially a win–win for agriculture and the aquatic ecosystems.

As with agriculture, the costs and benefits of mining and oil and gas extraction, however, are often misaligned with local communities and local ecosystems, which may bear the brunt of unsustainable practices (O'Rourke and Connolly 2003; see Rewa Village case study). Mineral seepage, contaminated wastewater, and dewatering (water is often a mining agent) are among the most detrimental impacts of mining and oil and gas extraction (e.g., hydraulic fracking) to inland fish and aquatic ecosystems (Younger and Wolkersforfer 2004). Mining can deoxygenate water bodies, change their pH, and increase levels of suspended solids, which can clog fish gills (Ashton et al. 2001). For oil and gas extraction, spills can have the most immediate environmental impacts, but water pollution from accidental discharge from refineries, hydrocarbons especially, can also significantly impact fish abundance and diversity (O'Rourke and Connolly 2003), as has been documented for sturgeon species in the Caspian Sea (Becker 2000). In addition to local impacts from the activities, transportation of oil and gas can result in distant impacts to inland fish if, for example, a pipeline ruptures.

Silviculture, the management of forested systems, can be as intensive as some agricultural practices, with similar water quality impacts. Clear-cutting, in particular, can be devastating for both terrestrial and aquatic ecosystems. Deforestation rates are particularly high in humid forests, which account for 54% of the net loss between the periods of 1990–2000 and 2000–2010 (Achard et al. 2014). Global estimates of tropical deforestation range from 50,000 to 170,000 km^2/year (Tucker and Townshend 2010). Deforestation near streams can change the structure, biomass, abundance, and functional diversity of fish communities (e.g., Bojsen and Barriga 2002; Lorion and Kennedy 2009; Dias et al. 2010; Teresa and Casatti 2012; Tanentzap et al. 2014). Not surprisingly, fewer insectivorous and omnivorous fishes that feed on forest-sourced organic material (e.g., wood, leaf litter, and terrestrial invertebrates) are found in deforested tropical streams than forested systems (Bojsen and Barriga 2002). In floodplain ecosystems, ongoing research suggests that the biomass of herbivorous fish increases as forest cover increases, and the converse as well, explaining the critical link between forests and fisheries (Naiman et al. 2002; C. C. Arantes and K. O. Winemiller, paper presented at the 100th annual meeting of the Ecological Society of America, 2015). In addition to forest benefits to fish, fish can also benefit forests. Helfield and Naiman (2001), for example, found increased growth rates of Sitka spruce near salmon spawning streams as a result of the nutrient influx from decaying salmon.

Aquaculture is the fastest-growing food production sector in the world and accounts for almost 50% of fish for human consumption (FAO 2014b) and is thereby increasing its requirement for both marine and freshwater resources. The contribution from aquaculture is expected to reach 47% of global fishery production and 53% of fish for human consumption by 2022 (FAO 2014b). In 2012, inland aquaculture represented 63% of the 66.66 million metric tons of farmed food fish produced globally (FAO 2014b). Inland aquaculture growth has outpaced that in marine waters because inland fish species are often easier to propagate and inland aquaculture can be more readily adapted in developing countries. For people in Asia, Africa, and Latin

America, inland aquaculture can be an easily available and important source of affordable animal protein and employment (FAO 2014b).

Inland aquaculture can be used to create new fisheries and, in some cases, can alleviate pressure on existing fisheries (Lorenzen et al. 2012). However, the two sectors do not often collaborate and can even compete for use of limited water resources. Aquaculture facilities, particularly conversion of inland waters to monoculture aquaculture facilities (e.g., in China), can also lead to environmental degradation and introduce diseases to inland fish (Lorenzen et al. 2012; see Wuhu Lake case study). Further, if not properly regulated, aquaculture facilities can create eutrophication problems, and escaped fish from these facilities often become invaders of natural systems (see Gondwe et al. 2011; Mekong Delta case study). Many of these environmental impacts of intensive aquaculture can be mitigated by judicious farm siting and operational controls. However, fish produced from aquaculture facilities for direct consumption often do not have the same nutritional profile as capture fisheries (Youn et al. 2014). Finally, capture fishers displaced by aquaculture often lack the financial capital to convert to aquaculture as an alternative livelihood, which can negatively impact local communities.

Recreation and tourism around inland water ecosystems creates one of the strongest social and political constituencies for environmental education and conservation of aquatic resources (Kearney 2002). Nevertheless, participants can change fisheries. Recreational anglers have a vested interest in conserving the aquatic resources upon which they depend. Often, through the nongovernmental groups to which they belong, anglers work proactively to conserve and enhance these resources by supporting environmental legislation; combatting illegal, unreported, and unregulated fishing; restoring aquatic habitat; and financing fisheries management. Recreational fishing can also have negative impacts if anglers, for example, introduce nonnative fishes (that might be of high interest for recreational fishing) or conduct unsustainable practices, such as harvesting undersized fish (Post et al. 2002). Local ownership and participation are critical to capture the conservation benefits of recreational fishing. Those who take up the sport in their youth and witness firsthand how fisheries change with environmental deterioration can become the greatest advocates for wise stewardship. Globally, a growing and better-educated middle class is becoming increasingly aware of the ecological consequences of unrestrained development. Anglers, fishing clubs, and lobbying groups are often at the forefront of these movements.

Global Drivers Impacting Water Systems

While inland fish and fisheries compete for water with other economically and socially important sectors, global drivers of change influence how all sectors, including water sectors, interact (Figure 1). These drivers (e.g., economic growth, diversifying economies, population growth, urbanization, and climate change) have synergistic and cumulative impacts. The drivers of change are particularly important to consider, notwithstanding that they are often beyond the scope of fisheries management but because they strongly influence the objectives and priorities for development and management of inland waters.

Economic growth (real gross domestic product [GDP]) is expected to increase in 2014–2015 from 3.1% in 2013, largely on account of economic recovery in the more advanced economies. Global growth is projected to increase from 3.25% in 2014 to 3.75% in 2015 to just less than 4% in 2016 (OECD 2014a). On average, real GDP growth rates were lower in the Organization for Economic Co-operation and Development (OECD) countries (1.7%) than globally (3.8%) in 2002–2011. The world economy is expected to be four times larger in 2050 than today, which could translate to an 80% increase in energy use, including hydropower (OECD 2012). If sustainable practices are not prioritized, dam construction, loss and degradation of aquatic habitat, water abstraction for consumption in agriculture, industry, and households, as well as drainage of wetlands and waste generation, will all impact fish and fisheries through reduced water availability and degraded spawning and nursery grounds.

Diversifying economies are altering the distribution of contributions from traditional sectors (e.g., agriculture, mining, and manufacturing) to service sectors (i.e., activities not associated with manufacture, mining, or agriculture). Between 1990–1992 and 2008–2010, the share of service economy in GDP rose from 66% to 74% for the OECD countries and from 44% to 51% for Brazil, Russia, India, Indonesia, China, and South Africa (BRIICS). The higher contribution of services to GDP was due in part to a shrinking agricultural sector, particularly in the BRIICS economies (–8%), as well as output contraction of the industrial sector, particularly in OECD countries (–8%). Marine and freshwater fishery products, the most traded food commodities, were worth almost \$130 × 10^9 in 2012 (FAO 2014b), and the structural change implies trade-offs between export-led growth and local food security provision. The world's lakes and rivers support globally important inland fisheries. Today in Europe, North America, and Australia, these water bodies are used mainly for recreation. In Africa, Asia, and Latin America, their primary value is in providing food and employment for tens of millions of people. Inland waters provide 33% of the world's small-scale fish catch and employ more than 60 million people, of whom 33 million are women (UNEP 2010).

For many local economies, inland capture fisheries are vital. Inland fisheries and aquaculture also provide jobs in ancillary services such as processing, packaging, marketing and distribution, provision of fish tackle, maintenance of fleets, research, and administration. About 20% of Southeast Asia's population is directly dependent on fisheries for their livelihoods, and an even larger share for protein intake (OECD 2014b). In the European Union, fisheries located in lakes and reservoirs account for more than half of the catch of inland fish in terms of volume, and 28% of the fishers work on lakes and reservoirs; estuaries and rivers involve a similar percentage of fishers (33%), but they only contribute to 17% of the catch by volume[1] (Newman 2014). Given the continued estimates of global economic growth, pressure will exist to further modify waterways at the expense of inland fisheries.

The expanding human population relies increasingly on inland fisheries to ensure food security. Total human population has increased from 5.3 × 10^9 globally in 1990 to 7.2 × 10^9 globally in 2013. Human population grew globally by 17% from 2000 to 2013 or by 35% from 1990 to 2013. By 2050, the world's human population is expected to reach 9 × 10^9. Demand for freshwater is expected to increase by 55% (OECD 2012), and demand for food by 60% by 2050 (Alexandratos and Bruinsma 2012). Furthermore, a larger share of this population growth is predicted to occur to a greater extent in BRIICS member countries, where reliance on inland fish for food security and livelihood is highest.

Urbanization has also been linked to increased competition for water and aquatic habitat through increases in industrial-scale farming and associated water use, as well as water quality issues associated with urban municipal water use. In 2014, 54% of the world's population resided in urban areas. In 1950, only 30% of the world's population was urban, but by 2050, 66% will live in or near cities (UN 2014). By 2030, the world is projected to have 41 megacities, each with more than 10 million inhabitants (UN 2014). With expansion of megacities near inland waters, urbanization will continue to fragment terres-

[1] Angling is the best-documented form of recreational fishing, and it was estimated in 2003 that there were at least 25 million recreational anglers in Europe. It was estimated that more than 20 million went freshwater fishing (Newman 2014). In 2006, it was estimated that spending on equipment, fees, lodging, and travel amounted to €19 × 10^9 in the EU27. The European Fishing Tackle Trade Association (EFTTA) estimated that more than €5 × 10^9 was spent on tackle trade and manufacturing in Europe alone, with about 52,000 jobs directly or indirectly benefited by this expenditure. With the inclusion of local tackle shops EFTTA estimates that about 99,000 jobs depend on tackle manufacturing and sales in Europe.

trial and aquatic habitats and place increasing environmental pressure on the fish resources as the amounts of waste and other population-induced effects concentrate around the available water.

Climate change is already influencing inland aquatic ecosystems and greenhouse gas (GHG) emission projections indicate that changes will continue (IPCC 2014). In 2010, global energy-related GHG emissions reached a record high of 49 × 10^9 metric tons (UNEP 2012), and the OECD baseline scenario projects that emissions will increase nearly four times by 2050. These anthropogenic GHG increases will drive warming atmosphere and ocean temperatures, reduced snow and ice, and rising sea levels (IPCC 2014). Dramatic changes in precipitation patterns have already been observed (Chou et al. 2013). These changes to environmental conditions will alter water quality and quantity and, consequently, aquatic habitat and fish production.

Case Studies: Searching for Sustainable Solutions

The five case studies from around the world (Figure 2) identify the variables on which decisions are made about inland water systems, explore management trade-offs, and identify how inland fisheries are considered in or impacted by decisions. Ultimately, the goal of these examples is to highlight discussion of trade-offs, identification of drivers, or integration of sectors that contributed to sustainability.

Recreational fishing for sustainable development in Rewa Village

Deep in the heart of the central Guyana rainforest, at the confluence of the Rewa and Rupununi rivers, lies the small Amerindian village of Rewa. Fewer than 300 people live in this tiny, remote enclave, but the Rupununi region is home to more than 400 species of fish, about 25% of which are found nowhere else in the world. Foremost among these endemic species are arapaima (*Arapaima* spp.), the largest scaled freshwater fish on Earth.

Until recently, multiple sectors, including oil drilling, gold mining, diamond mining, logging, agriculture, and fisheries, have degraded aquatic habitat and threatened arapaima and other species. The people of Rewa were dependent upon these sectors for their livelihoods. But with support from the international donor community, Rewa invested in alternative development strategies to support livelihoods and conservation of their important fishery resources. In 2005, Rewa opened an ecolodge with a grant provided by Conservation International. The village of Rewa owns and operates the ecolodge. Approximately 80% of the villagers are employed there, working in shifts. The staff members are 100% Guyanese with the exception of one guide who is a fly-fishing expert and is only present when the lodge is hosting fly-fishing tourists. The lodge is open for 6 months per year, with more than 500 visitors.

The community of Rewa capitalized on their valuable aquatic resources to develop a profitable recreational fishing and tourism industry. The revenue generated from fishing trips alone covers the lodge's operational costs. This shift in livelihoods was a win–win for the local economy and for aquatic conservation (Table 1). By considering both the social and economic needs of the community, as well as the conservation of their fishery resources, the community was able to improve both their economic condition and the quality of their fishery resources.

Enhancing the resilience of Lake Cyohoha communities to climate change

Lake Cyohoha is in a transboundary catchment located in the Bugesera region between Burundi and Rwanda. It falls within the Kagera subbasin of the Lake Victoria basin, which is part of the wider Nile basin. Agriculture, mostly rain-fed, is the most important livelihood for communities in the catchment, employing more than 90% of the population within the subbasin. Food insecurity is a major problem, mainly due to the small size of farming plots, poor agricultural practices, increasing human populations, and land degradation. Access to basic services such as clean water, sanitation, health services, and primary education is very poor. A legacy of civil wars and political instability contributes to cross-border migration, resulting in unplanned settlements and further degradation of the environment. Climate change also poses a growing threat (e.g., floods, droughts) to development and to the well-being of communities in the catchment and sustainability of their fisheries resources.

In the face of these threats, the local authorities and communities understand that adaptive actions will be necessary to enhance the resilience of the Lake Cyohoha catchment to climate change. Using an ecosystem approach, they are promoting integrated management of land, water, and natural resources for climate adaptation by conducting a catchment-wide assessment for Lake Cyohoha; establishing a transboundary catchment management structure; supporting local actions for climate resilience; strengthening capacities of stakeholders to engage in management; documenting processes and lessons for scaling up in Burundi, Rwanda, and other east African countries; and enhancing catchment-wide partnerships. Through these efforts to enhance resiliency, the Lake Cyohoha communities have concluded that the catchment/basin is the most appropriate unit for management and cooperation because communities all need water and other natural resources for various uses (e.g., agriculture, fisheries, energy, drinking, and washing) at that scale. Early participation and ownership of the processes by all stakeholders (e.g., local authorities, communities, farmers, and fishers associations) empowers the participants, helps ensure buy-in, and promotes water security and climate resilience.

Lake Cyohoha faces impacts from global drivers, such as climate change, beyond local control. However, the local communities have adopted comanagement approaches to address their most immediate needs while maximizing their resilience to drivers beyond their ability to manage (Table 1). Both local knowledge and global hydroclimatic models have been useful for linking policy to practice. Through these synergistic strategies, they have developed integrated cross-sectoral approaches to manage water systems for all fishery and nonfishery sectors and promote water security and climate resilience within the Lake Cyohoha catchment.

Restoration of Lake Rupa by cooperative management

Lake Rupa is a small, subtropical, shallow lake with a surface area of 100 ha situated 600 m above sea level in central Himalaya, Nepal. It was classified as a diminishing lake in 1999. Land-use practices in the catchment led to sedimentation and excessive growth of rooted aquatic vegetation in Lake Rupa. Without strong local management institutions, the lake condition precipitously declined. Motivated to improve their lake and its fishery resources, 329 local families formed a lake cooperative in 2002. The cooperative's major goal was to conserve, manage, and enhance the lake's fisheries to benefit the community (Table 1).

Due to the action-oriented work of the cooperative's members, the aquatic weeds were removed and are now under control and lake fisheries have improved (Gurung 2007). The local communities have gained more awareness of the importance of water, the lake, and related resources. Additionally, the fishery has benefited economically from the cooperative's efforts. In 2014, cooperative membership increased to 755 families, and fish sales by the cooperative totaled around 0.85 million Nepalese rupees (almost $8,000) in 2014. Annually, profits have been distributed to members of the cooperative. The cooperative has its own savings account, has used the funds to establish a native fish hatchery near the lake, and has several plans for future restoration and development projects.

The Lake Rupa fishing community recognized that their livelihoods were dependent on factors external to their fishery. Where traditional management strategies were not available to them, they self-organized and formed a collective. The lake cooperative has been able to improve lake condition, lake awareness, and fisheries productivity.

Ecosystem-remediation-based lake fisheries in Wuhu Lake

China has the largest freshwater aquaculture industry in the world, accounting for more than 60% of global aquaculture (FAO 2014b). In China, almost all inland water bodies, including ponds, lakes, rivers, and reservoirs, are used for aquaculture. In reservoirs and lakes, the most common aquaculture practice is net-cage or enclosure culture. There is a huge diversity in cage size and material used to construct net cages, as well as the species cultured. In some lakes and reservoirs, fertilizers are used to culture plankton to support production of planktivorous fish such as Silver Carp *Hypophthalmichthys molitrix* and Bighead Carp *H. nobilis*, and this often leads to eutrophication and environmental deterioration.

Lakes, amounting to 34% of the total freshwater surface area in China, are important resources both for fisheries and for other uses (e.g., agriculture). Many fish species are stocked into lakes to increase aquaculture production. The most common species are the Chinese carps (i.e., Silver Carp, Bighead Carp, Grass Carp *Ctenopharyngodon idella*, and Black Carp *Mylopharyngodon piceus*). In recent years, a trade-off between aquaculture production and environmental protection has been applied in some lakes, such as Wuhu Lake. Managers switched to stocking higher-valued species such as Mandarinfish *Siniperca chuatsi*, Mitten Crab *Eriocheir sinensis*, and Yellow Catfish *Tachysurus fulvidraco* from the more intensive culture of the Common Carp *Cyprinus carpio*.

Through this change in management strategy, Wuhu Lake managers were able to remediate the lake ecosystem condition by reduced aquaculture intensity, but still maintain profitability through the stocked higher-value fisheries (Table 1). In short, overall production is lowered but overall value is elevated. Ultimately, this system seeks to balance the value of environmental protection and economic benefit of the increasingly desirable culture-based fisheries.

Intensive inland aquaculture production and minimizing ecosystem impacts in the Mekong Delta

The Mekong Delta is one of the largest wetland systems in the world, playing an important role in local livelihoods and socioeconomic development. Second only to rice production, aquaculture is a primary economic activity in the Mekong Delta and brings major foreign investment into Vietnam. In recent years, potential profits from the culture of catfish and shrimp have led many fruit farms and rice fields to convert to industrial aquaculture farms.

During the past 10 years, about 250,000 ha of fertile land that supported rice farming in the coastal Mekong Delta were converted to shrimp farming. This has changed the fabric of the local economy, significantly increased income, and improved people’s lives. But it has also caused negative effects, including ecological changes (e.g., declines in local fish, water pollution, saltwater intrusion) and increased risk of disease outbreaks (e.g., early mortality disease, white spot, or pancreatic necrosis liver disease in cultured shrimp). Deterioration of the environment is cited as one cause for the disease outbreak events.

Aquaculture makes significant contributions to socioeconomic development in the Mekong Delta, but it also directly or indirectly has negative impacts, leading to conflicts between stakeholders. To address these issues, the Vietnamese government and many nongovernmental organizations have collaboratively issued an aquaculture master plan and provided support for many projects to treat waste from catfish and shrimp ponds (Nguyen 2011). The aquaculture master plan recognizes that to develop sustainable aquaculture, the sustainability of aquatic ecosystems should be the top priority, and that economic benefits can result from conserving and protecting healthy ecosystems (Table 1). As a result, healthy aquatic ecosystems will sustain a higher quality of life for the farmers, their families, rural labor, and all communities involved.

The Way Forward

Even as the case studies provide specific examples of how management can create win–win situations that benefit fisheries, other water-resource users, and aquatic ecosystems, there are a number of key issues that hinder inclusion of inland fisheries in water-resource management decisions. Indeed, the diversity of inland fisheries within complicated water-resource management frameworks means that strict, prescriptive solutions to enhance the consideration of fish and fisheries are unlikely to be of particular value. Rather, the issues described here are purposefully broad as are the pathways proposed to overcoming them, though specific examples can provide more context (see Table 1).

Overall, the omission of inland fisheries in discussions about water use needs to be addressed. Without being involved in discussions, it is very likely that impacts on inland fisheries will only be addressed post hoc and potential synergies will not be optimized. The inland fisheries sector is not specifically included in the United Nations Economic and Social Council post-2015 development agenda (www.un.org/sustainabledevelopment/sustainable-development-goals/). It should be. Inland fisheries are relevant and significantly contribute directly to at least four sustainable development goals (SDG): (1) no hunger (SDG2)—in rural, poor regions, inland fisheries can be the primary source of food, essential nutrients, and livelihood (Welcomme et al. 2010); (2) no poverty (SDG1)—inland fisheries provide livelihoods for more than 60 million people, mostly in low-income countries (FAO 2014b); (3) gender equality (SDG5)—frequently, women are in charge of postcatch handling of fish, including selling and marketing (FAO 2014b); and (4) life on land (SD15)—inland fish production is linked to the health of catchment-wide aquatic and terrestrial ecosystems and to preserve fish production will invariably require steps to protect the environment (Dudgeon et al. 2006). It is worth noting that inland waters do not have a standalone goal like marine systems—life below water (SD14). More explicit inclusion of inland fisheries in the sustainable development agenda will set a powerful example for its inclusions at other global, regional, and local discussions.

Environmental management has a legacy of approaching natural resources independent of the system and disregarding the effects on dependent processes. In water management, it has been common for riverine systems to be managed for specific, and often single, purposes (e.g., the construction of dams for irrigation or agriculture; Loth 2004). The consequences of these implementation practices are not always considered, and often, a post hoc amending project is required to mitigate some of the negative impacts on other essential processes (Loth 2004; Ziv et al. 2012). Though there has been a move to develop and incorporate multisectoral water-use management approaches, these actions should continue to be encouraged and adopted from the beginning of any water management proposals. The European Water Framework Directive (European Parliament 2000) and the Lake Cyohoha case study are successful multisectoral approaches to water management that include the health of fish and fisheries.

An inclusive water management proposal requires effective communication between stakeholders to align water management across their various objectives. This can be a challenge in a multisector system, as stakeholder variation can arise from views from different competing sectors (e.g., hydropower versus inland fisheries) and across both physical (e.g., aquaculture farms versus migrating fish stocks) and user scales (e.g., individual, subsistence fishers versus multinational fishing companies). This variation often, but not always, leads to differing objectives and also to alternative language and terminology. Participatory approaches, such as the Lake Rupa case study, can be used to foster stakeholder communication for an inclusive water management program. Furthermore, future cross-sectoral collaboration may become more the norm the longer these relationships and communication channels are fostered.

Once involved in water-use discussions, inland fisheries stakeholders must use the opportunity to identify synergies with other sectors. Given the often small stature of inland fisheries within the water sector network, it is difficult to envisage a situation where the objectives of inland fisheries will dictate or lead discussions. Thus, it is more likely that inland fishery objectives will be achieved through a cooperative, synergistic strategy and a search for win–wins with other sectors, such as the Rewa Village, Wuhu Lake, and Mekong Delta case studies. If these are not possible, it will then be prudent to work towards proposals minimizing losses to the inland fisheries sector. Approaches like the Institutional Analysis and Development Framework (Ostrom 1990, 2011) can assist in providing a structure to assess policy choices for multiple users and water sectors.

The above issues can be argued to be a result of the perceived trivial economic value of inland fisheries compared to other water sectors, making the inland fisheries sector secondary in policy discussions. Assessing inland fisheries production is inherently a difficult process; most inland fisheries activity is small-scale, highly dispersed, and generally unreported to governmental agencies (see Cooke et al. 2016, this volume). However, current estimates undervalue the total socioeconomic contribution of inland fisheries, including cultural and biological contributions (See Youn et al. 2016). A robust estimate of the true value of inland fisheries will be an important tool to both raise awareness so the sector is involved in discussions and provide a quantitative basis for negotiations with other sectors. While improving the quality of valuation inland fisheries is an internal challenge, and some regions have had successes (e.g., lower Mekong Delta, Baran et al. 2007), it is possible that solutions can be sought externally following the example of other sectors. Benefit–cost ratio targeting, for example, has been used to optimize agricultural land use and conservation benefits (e.g., Duke et al. 2014).

With better recognition of the value of inland fisheries, inland fishery governance needs to adjust and address the discrepancy in fishery value and the consideration given to fisheries in resource management decisions (See Bartley et al. 2016, this volume). Currently, inland fisheries are not even included in development goals. Generally, the issue is twofold: first, the value and contribution of inland fisheries needs to be better assessed so future decisions are grounded in factual arguments, and second, the complexities of the cross-sectoral water resource management landscape mean inland fisheries are often crowded out. Instead of trying to dictate the conversation, inland fisheries may benefit more from identifying potential synergistic relationships (i.e., win–win scenarios). This may result in more ecologically and socially sustainable approaches to water management and ultimately improve the health, well-being, and prosperity of fisheries-dependent communities.

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Rehabilitating Fishes of the Murray–Darling Basin, Australia: Politics and People, Successes and Failures

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Abstract.—The Murray–Darling basin (MDB) in southeastern Australia, covers 1.1 million km^2, involves six partner jurisdictions with a myriad of different government agencies, and, hence, provides an excellent example of the complexities of multijurisdictional management across a range of social and political tiers. In the MDB, fish and fisheries compete for water with agriculture, which is the traditional water user and is driven by national economics. Murray–Darling basin rivers are now highly regulated and generally in poor health, with native fish populations estimated to be at only about 10% of their pre-European settlement abundances. All native commercial fisheries are now closed, and the only harvest is by a recreational fishery. The six partner jurisdictions developed a Native Fish Strategy (NFS) to rehabilitate native fish populations to 60% of pre-European settlement levels after 50 years of implementation by addressing priority threats through a coordinated, long-term, whole-of-fish-community (all native fishes) approach. As there are a wide range of stakeholders, broad engagement was needed at a broad range of government and community levels. The NFS funding was discontinued after 10 years, not because of its lack of successes or project governance, but due to jurisdictional political changes and funding cuts that resulted in a failure of the collaborative funding structure. The withdrawal of considerable funding by one jurisdiction led to collective decline in monetary contributions and posed a threat to the multijurisdictional structures for both water and natural resource management (NRM) within the MDB. As a consequence, there was a review and reduction in NRM programs and a subsequent reduction in focus to the core business of water delivery. Reflection on the NFS, however, provides some useful insights as to the successes (many) and failures (funding) of this partnership model. Overall, the strategy and its structure was effective, as exhibited by an audit of outputs, outcomes, and networks; by the evident ongoing advocacy by NRM practitioners and the community; and by the continuation of ideas under other funding opportunities. This has provided a powerful legacy for future management of fishes in the MDB.

Introduction

As the world's driest inhabited continent, Australia magnifies many key issues relating to water usage and environmental management, especially fish and fisheries. This climatic and hydrological variability has stimulated high investment in water storage and irrigation infrastructure, particularly in the Murray–Darling basin (MDB), southeastern Australia (Figure 1), where demands for water for agriculture compete with the allocation of water for environmental requirements. This economic claim and the potential overallocation of water (Lester et al. 2011) has resulted in significant ecological pressure on aquatic systems, with high

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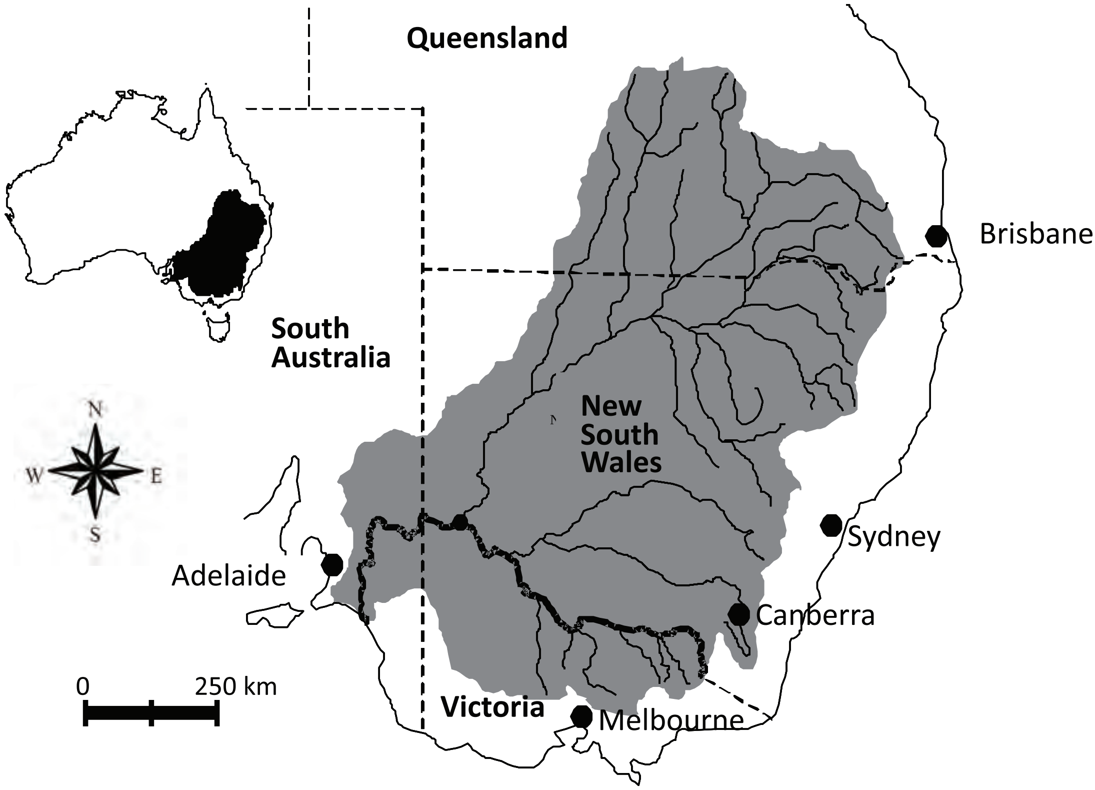

Figure 1.—Map of the Murray–Darling basin (grey shaded area) in southeastern Australia.

levels of flow regulation, water abstraction, and floodplain and riparian modification (Murray–Darling Basin Commission 2004). There have recently been major reforms to provide more water for the environment (The Basin Plan; Koehn et al. 2014a; Murray–Darling Basin Authority, Basin Plan, www.mdba.gov.au/basin-plan), and this remains a politically sensitive issue (Koehn 2015). In parallel, the Native Fish Strategy (NFS) for the Murray–Darling Basin 2003–2013 was developed to rehabilitate the native fishes of the MDB by addressing a range of other threats in addition to flows (Koehn and Lintermans 2102).

The MDB covers 1.1 million km^2 or 14% of Australia's land area and is governed by six partner jurisdictions: four states (South Australia, Victoria, New South Wales, and Queensland), a territory (Australian Capital Territory; Figure 1), and the national government. These respective governments have a myriad of different departments and agencies that have varied and disparate responsibilities, goals, and objectives providing considerable challenges to effective natural resource management, especially for fish and fisheries (Koehn and Lintermans 2012). Water use and management is coordinated across jurisdictions through the Murray–Darling Basin Authority (MDBA). The MDBA comprises committees of ministers and departmental representatives from jurisdictions, as well as the Basin Community Committee, consisting of community members from the basin's water users, indigenous peoples, farming, and environmental water management sectors (www.mdba.gov.au/about-us). Most of the funding for the MDBA comes from collective state contributions. Despite the MDBA's coordinating role with respect to water, most natural resource management (NRM), including most rivers and fish populations, is the prime responsibility of various state departments, among which there can often be a lack of coordination.

This paper illustrates the multijurisdictional governance of the MDB and the arrangements used to engage the wide range of stakeholders and agencies in a partnership model for the rehabilitation of fishes. It assesses the successes and failures of the program and makes suggestions to address the obstacles identified.

Native Fish Populations

Assessment of the health of rivers in the MDB indicates that 19 of 23 river valleys are rated to be in “poor” to “extremely poor” ecological condition (Davies et al. 2010). Native fish populations have suffered substantial declines and are now estimated to be at about 10% of their pre-European settlement (mid-1800s) levels (Murray–Darling Basin Commission 2004). All freshwater commercial fisheries for native species have been closed with harvest now only from the recreational fishery. Despite their diminished status, native fishes still have important ecological, social, cultural, and economic values and provide a key link between the community and their waterways, particularly so for Aboriginal and rural Australians, such as within the MDB (Koehn 2015). Aboriginal people have many important cultural connections to MDB fish species (Rowland 2005; Ginns 2012). Recreational fishing is an important pastime in Australia, with a participation rate of almost 20% nationwide and higher in rural areas such as the MDB (Henry and Lyle 2003). Recreational fishing contributes significantly to tourism, providing economic benefits to many rural areas (Ernst and Young 2011).

The Native Fish Strategy

The dire state of freshwater fish populations provided the community and agency impetus that resulted in the MDBA developing the NFS to attempt to rehabilitate native fish populations (Murray–Darling Basin Commission 2004). The NFS was a commitment between all partner jurisdictions to address existing threats to fishes (Murray–Darling Basin Commission 2004), this being undertaken within the existing MDB agreement and management structures (Figure 2). The NFS has been described and evaluated in detail by Koehn and Lintermans (2012) and Koehn et al. (2014b). Project level governance was undertaken by a NFS advisory panel (NFSAP) (Figure 2; Koehn and Lintermans 2012) that consisted of a policy and science representative from each

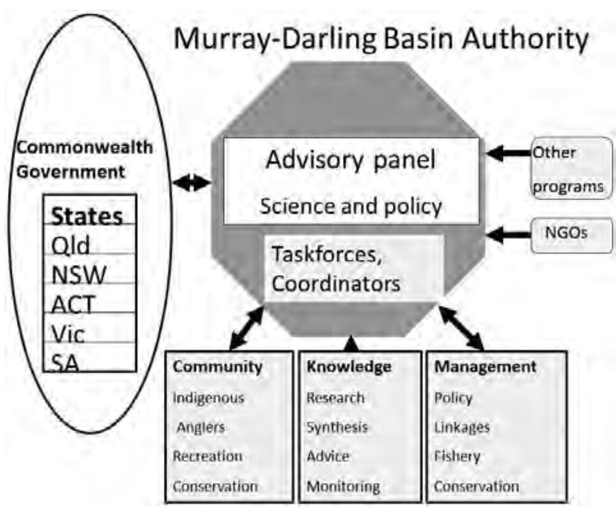

Figure 2.—Management structure for the Native Fish Strategy. Shading indicates Murray–Darling Basin Authority components. NGOs = nongovernment organizations. (Adapted from Koehn and Lintermans 2012).

state together with representatives from the MDBA and major agencies of the national government, supported by number of discipline-specific task forces, each with clear roles and responsibilities (Figure 3; Table 1). Each task force included MDBA staff and an independent scientist and ensured jurisdictional representation (often NFSAP members).

One task force (Community Stakeholder Taskforce) focused on engagement of the community as their involvement and support was important, and this was a significant new component to the management of fish in Australia (Hames et al. 2014). Strong engagement was necessary across the range of social, political, and departmental organizational tiers, especially with communities, stakeholders, and jurisdictional agencies. Importantly, there was a need for this engagement to be undertaken by advocates appropriate for the tier of government department or agency (see Table 2). Full-time, dedicated NFS coordinators were appointed in each state to engage with a variety of stakeholders through a formal communication strategy, link research and projects to management, act as knowledge brokers, work directly on projects, embed fish into wider catchment management programs, and form links between agencies and jurisdictions. Their engagement tended to be focused towards NRM practitioners, researchers, key interest groups, the education sector, and the broader community. The NFS also established and engaged the community and other stakeholders through demonstration reaches, partnership projects with the community and relevant agencies where a series of restorative actions were applied and rigorously evaluat-

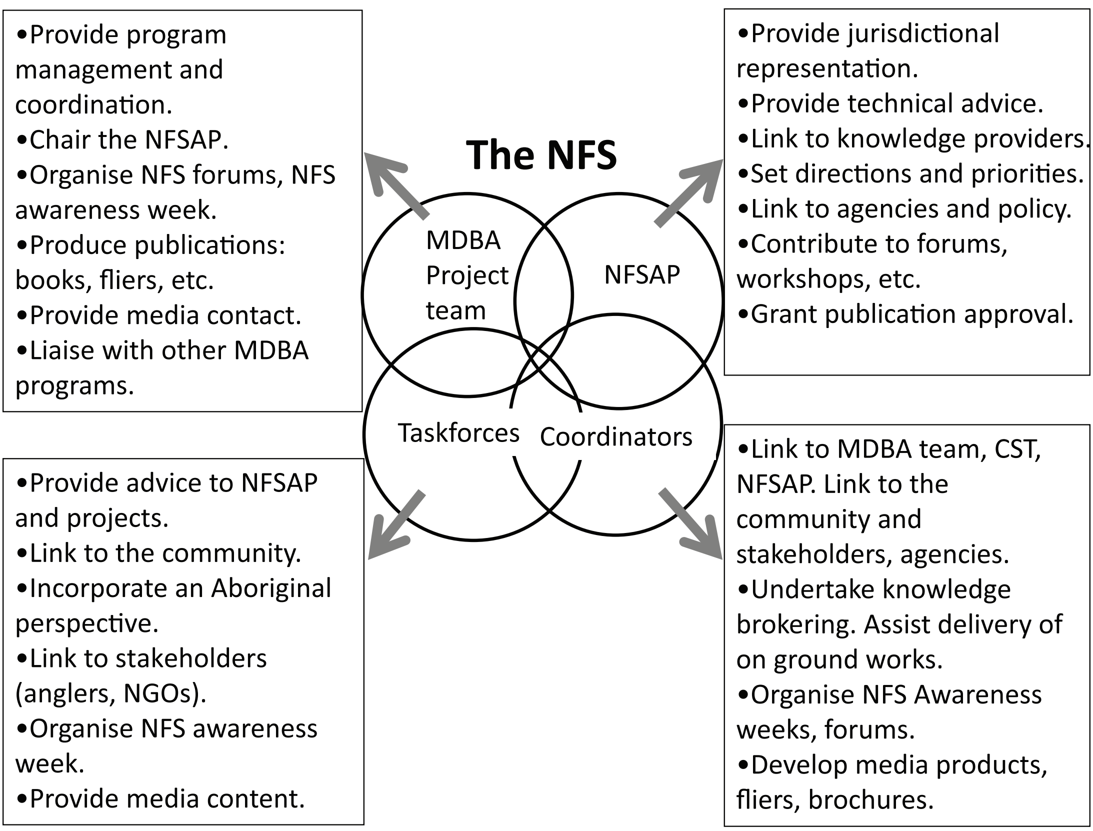

Figure 3.—Roles and responsibilities of the Murray–Darling Basin Authority (MDBA) Native Fish Strategy (NFS) project team, NFS advisory panel (NFSAP), task forces, and NFS coordinators. (Adapted from Koehn et al. 2014b).

Table 1.—Native Fish Strategy (NFS) advisory panel and taskforces, their membership and purpose.

	Membership	Purpose
NFS advisory panel	One policy representative and one fish scientist from each state, representatives from key national agencies, a member of the Community Stakeholder taskforce, an independent scientist.	Provide jurisdictional representation, link between organizations, develop action plans, set directions and priorities, review projects and all technical outputs, provide advice and progress on fish issues.
Taskforces		
Community stakeholder	Recreational fishers, regional angler/tackle shops, conservation, community and indigenous representatives, Murray–Darling Basin Authority staff, NFS coordinators.	Provide community and stakeholder representation, contribute to community events such as school visits and native fish awareness week.
Alien fish	Alien species scientists, managers.	Coordinate and contribute to the Alien Fish Management Plan for the Murray–Darling basin.
Fish passage	Engineers, river operators, fish scientists, fish passage experts.	To design, manage, oversee construction, and monitor the Sea to Lake Hume fishway program (see Barrett and Mallen-Cooper 2006; Barrett 2008; Baumgartner et al. 2014).
Demonstration reach	NFS coordinators, fish scientists, water and land managers.	To develop and coordinate demonstrations reaches (see Barrett 2004; Boys et al. 2014; Hames et al. 2014).
Habitat management areas	Conservation, water and land managers, fish scientists.	To develop an approach to the politically sensitive issue of managing important habitat areas.
Recreational fishing	Fishery manager and recreational fishers.	To ensure that the NFS supports the needs of recreational fishers (Barwick et al. 2014).
Murray Cod	Fish conservation and fisheries scientists and managers; state recreational fishers representatives.	Provided inputs and acted as a steering committee for the formulation of the national Murray Cod Recovery Plan (see National Murray Cod Recovery Team 2010).

ed to illustrate the value of integrated action on multiple threats in a river reach (Barrett 2004; Boys et al. 2014).

Assessment of Successes and Failures

The cessation of funding for the NFS in 2013 has allowed this paper to undertake an evaluation of all areas of the program with the benefit of hindsight. This evaluation is in addition to a comprehensive, external, 5-year review (Cottingham et al. 2009) that concluded that while the NFS had been successful in the delivery of programs (albeit under a limited budget and, therefore, limited scale of operations), activities would need to be increased if basin-scale changes were to be detected in the time frame of the strategy (Koehn et al. 2014b). The enormity of the rehabilitation task always posed some difficulties, as while the 50-year time frame was accepted as real-

Table 2.—Tiers of engagement for the Native Fish Strategy (NFS). NFSAP = Native Fish Strategy advisory panel; MDBA = Murray–Darling Basin Authority.

Sector	Tier/level	Appropriate NFS advocate
Community	Schools	NFS project officers, coordinators, taskforces
	Land care	NFS project officers, coordinators, taskforces
	Recreational fishers	NFS project officers, coordinators, taskforces
	Indigenous	NFS project officers, coordinators, taskforces
	General public	NFS project officers, coordinators, taskforces
	Media	NFS project officers, coordinators, champions
Natural resource management practitioners	Catchment authorities	Coordinators, taskforces, NFSAP
	Departmental regions	Coordinators, taskforces, NFSAP
Science	Scientists	NFS project officers, NFSAP
	Consultants	NFS project officers
	Knowledge	NFS project officers, NFSAP
Government agencies	Policy	CEO level of MDBA
	Management	NFS project officers
	Operational staff	NFS project officers
Political	Departmental heads	CEO level of MDBA, champions
	Politicians	CEO level of MDBA, champions

istic and necessary, there was a reluctance to commit to long-term funding.

The vision for the NFS was to sustain viable fish populations and communities throughout its rivers. The overall, aspirational goal was to rehabilitate native fish communities in the MDB back to 60% or better of their estimated pre-European settlement levels after 50 years of implementation. Whist this explicitly stated goal was controversial and caused some nervousness within departments who were reluctant to be held to such a commitment, it was embraced by the public as a realistic and tangible guarantee for action. This simple, commonly accepted, readily identifiable goal became a significant driver for the NFS and was encompassed by the slogan "Bringing Native Fish Back."

The community and recreational fishers indicated that they clearly recognized the need to rehabilitate native freshwater fishes in the MDB. There was, however, a more mixed response from agencies and departments, depending on their core business and fear of making long-term funding commitments. Water policy managers also failed to recognize that fish could be a key way to illustrate benefits of the water reforms of The Basin Plan and improved environmental outcomes (Koehn 2015). While engagement at the community level was well accepted and ongoing, engagement and familiarity with the NFS at higher departmental and political levels dissipated over time with staff turnover, organizational changes and restructures, and the need for politically "new" programs. Beyond the initial establishment of the NFS, the responsibility for building advocacy at higher political levels was never fully articulated or included in the formal engagement strategies, and thus effort declined over time. This neglect of effort to continually engage at these higher departmental and political levels was ultimately detrimental to the NFS (Koehn and Lintermans 2012). The development of supporting relationships takes time, and the combined support for the NFS from the traditionally disparate (and potentially opposing) groups of recreational anglers, the National Irrigators Association, and the Australian Conservation Foundation did indicate belated success in this area. Such support was probably needed but realistically unattainable much earlier in the program (Koehn et al. 2014b).

One significant achievement from the NFS and its engagement with the community was that there is greater community awareness and recognition of the need to rehabilitate waterways of the MDB to recover native fish populations. The NFS did provide many "good news" media stories that generated public interest, and a dedicated communication strategy that identified methods to inform and engage different stakeholders was valuable. The use of champions, recognized authoritative enthusiasts, willing and able to speak to the media to promote native fish was powerful when applied. Nevertheless, the more extensive engagement of high-profile champions may have provided more media coverage and publicity to the broad community, senior government officials, and politicians. Recreational fishers and their organizations could have been engaged earlier to provide influential political support. The inclusion of an oral history project (e.g., Trueman 2011) proved useful for further community engagement.

While NFS messages were greatly enhanced by the use of Murray Cod *Maccullochella peelii* and other iconic fish species, this was not so for water reform in general. Their use as important components of river health could have helped engender community ownership of water reforms through shared ecological objectives relating to improved fish populations and angling opportunities (Koehn and Todd 2012). Community support needs to come from both local populations (usually rural) and those more distant. While the population of the MDB is about 2 million people, an additional 10 million people live in capital cities and nearby population centers that also have an interest in the MDB and its fishes, as they either travel there as fishers or tourists or just care that fish are there and being properly managed. This capital mass of the urban communities was not engaged early enough to provide the support to the strategy when it was ultimately needed. In the years since the defunding of the NFS, however, there has been considerable representation at political levels for its reinstatement.

The NFS Research and Development Program delivered approximately 100 projects between 2002 and 2011 at a cost of more than Aus$12 million (project summaries at www.finterest.com.au) and, with them, key advances in knowledge to assist in recovering native fish (see Koehn et al. 2014b). The lessons learned have not been lost due to a thorough knowledge synthesis (Barrett at al. 2013), the creation of a NFS legacy Web site (www.finterest.com.au), and a compilation of journal papers (*Ecological Management and Restoration* 15, supplement 1), ensuring that most of the NFS knowledge generated is available for future programs. Demonstration reaches, where multiple interventions were practiced, were highly successful and have continued with a variety of regional funding initiatives. The kudos earned by the Condamine Alliance for their demonstration reach (2012 Banksia Award for Water, 2013 Australian Riverprize, 2013 United Nations Association of Australia World Environment Day Award for Biodiversity) not only points to success at this site, but to broader recognition of the value of this concept. Powerful and ongoing understanding of the principles of the NFS and ongoing advocacy remains evident among many communities and among many NRM individuals and agencies.

Discussion

There is no doubt about the on-ground success of the coordinated approach to fish management in the MDB. While an integrated approach to water management was already applied across jurisdictions by the MDBA, the additional layers of community, science, and management for fish were beneficial. Although not unique in fisheries management, the formation of the NFSAP, supported by technical task forces relating to particular objectives was a new and workable model for the MDB. Coordination of the NFS (and chairing of the NFSAP) by an independent (nonstate) agency also facilitated a nonpartisan, collective, consensus approach.

The success of the NFS was also principally due to the continued enthusiasm and long-term commitment of MDBA NFS staff, state-based NFS coordinators, NFSAP members, and researchers who agreed with the NFS vision.

This "staying the course" built an NFS family of committed individuals and organizations that allowed corporate memory to build and to be utilized in efficient delivery of projects. Although some personnel moved into other areas, there remains a commitment by many to attempt to continue the networks and priorities under other arrangements, although it is recognized that in some areas this is diminishing over time. Some of the networks developed have endured and been utilized within other MDB programs, such as incorporating fish and environmental flows (Koehn et al. 2014a). The Australian Fisheries Management Forum (chief executives of all Australian fisheries management agencies) has also now formed a native fish working group, and although this has a more recreational fishery focus, it does continue some aspects of the NFS. Many regional NRM and catchment agencies continue components of the NFS; indeed one Catchment Management Authority has recently launched its own regional native fish strategy.

Ultimately, the NFS ceased after it first 10 years, not because of its lack of project successes, but due to a failure of collaborative funding at higher political levels. This funding structure meant that the budget was susceptible to withdrawal of funding by any one of the five state contributing jurisdictions. Sufficient funding is always a risk to project implementation and success, and longer-term funding commitments are needed, beyond a year-to-year basis, to ensure continuity. Although these are unlikely for the 50 years envisaged for this strategy, decadal funding would be more appropriate for such long-term rehabilitation. Mechanisms to broaden stakeholder investment to balance against government-only funding may have ensured wider support and reduced risks of single-agency funding-cut decisions (see Koehn and Lintermans 2012).

There is no doubt that the NFS improved the way that fish are managed in the MDB. Some of the governance structures and methods used in this example, where the NFS endeavored to rehabilitate native fish populations, may also be adapted to other multijurisdictional fisheries. Ultimately, any program can be at the whim of overriding politics and, hence funding cuts, unless long-term agreements are securely in place. The need to rehabilitate native fish populations in the MDB remains, however, and the efforts that have been made to secure the networks, legacies, and lessons from NFS have laid the foundations for future fish recovery actions.

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Review of the Decline in Freshwater Natural Resources and Future of Inland Fisheries and Aquaculture: Threatened Livelihood and Food Security in Indus Valley, Pakistan

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Abstract.—Pakistan is blessed with an abundance of diverse natural resources. The Indus River and its rich agriculture valley with five tributaries is the world's largest man-made irrigation network of canals. Earth-filled dams and barrages are commonly used across an estuary to capture tidal power from tidal inflows. The Indus River watershed also includes freshwater lakes, floodplains, and waterlogged areas. Inland aquaculture ponds are fast emerging in the Indus River.

The sustainability and historic agricultural superiority of Indus Valley agriculture due to the use of water from the Indus River for irrigation for 5,000 years are now under severe threat due to a rapid population explosion of 200 million people. In addition, the Indus River is also threatened by the release of untreated industrial and municipal effluents into the Indus River and other freshwaters, increasing salinity, waterlogging as a result of ice melting and an increase in water table, global warming, drought, and poor management, which have led to degraded aquatic habitats and unhealthy, collapsing artisanal fisheries.

Pakistan is at high risk of food insecurity in the coming decades because of drought and climate change. It is universally believed that climate change will impact future freshwater availability and ultimately the freshwater fish and fisheries. This paper discusses growing food insecurity, a decline in inland fisheries, and the ecological degradation of freshwater in the Indus River system, Pakistan.

This paper suggests alternate mitigation efforts, such as aquaculture, to compensate for the decline in freshwater capture fisheries, to address the growing threats to livelihoods and food security of the poor inland fishing community.

Introduction

The Indus River is a vital lifeline and source of freshwater supply in Pakistan for agriculture, fisheries, industrial use, and human consumption. The Indus River extends from the Himalayas in the north to the Arabian Sea in the south, with a unique range of geographical and geological features and biodiversity, covering mountains, plains, and deltaic environments. The Indus River also has great global significance from an archaeological point of view as Mohenjo-Daro is one of the oldest civilizations along the river. Today, the river provides 80% of all the water consumed in Pakistan. More than 70% of the water in the Indus River comes from the glaciers and high-altitude wetlands. It has a total drainage area of 1,165,000 km^2, of which 712,000 km^2 lies in Pakistan. Its annual flow is 207×10^9 m^3, which is twice that of the Nile River and thrice that of the Tigris and Euphrates rivers combined. The Indus River supplies irrigation water for about 45 million acres (18.2 million ha) of land, which accounts for 80% of the total arable land of the country.

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Almost 180 million people are directly or indirectly dependent on the Indus River system (Nasir and Akbar 2012).

Agriculture and irrigation are the hallmarks of the famous Indus Valley civilization of Mohenjo-Daro (4500–2500 BC) resulting from the freshwater natural resources of the Indus River system, which brings freshwater and fertile soil and silt down from the Himalayan mountain glaciers. Today, Pakistan is one of the world's largest producers of cotton (fourth), wheat (seventh), rice (fourteenth), sugarcane (fifth), chickpeas (third), milk (fifth), onions (seventh), apricots (sixth), date palms (fifth), mandarin oranges (sixth), and mangos (seventh).

The Indus River originates in western Tibet and flows northwest through mountain gorges of northern Pakistan before entering the fertile plains of Punjab and Sindh. Five eastern tributaries, the Beas, Sutlej, Ravi, Chenab, and Jhelum rivers, rise in the mountains of Kashmir and bring huge floods during monsoon rainfalls (Figure 1). The Indus Water Treaty (1960) between India and Pakistan allocates exclusive use of the Indus, Jhelum, and Chenab rivers to Pakistan and exclusive use of the eastern rivers—Ravi, Sutlej, and Beas—to India (Figure 2). Pressure for agricultural irrigation and needs for hydropower generation grossly changed the inland fisheries and freshwater ecology of the Indus River and its tributaries as a result of increased river fragmentation, construction of barrages, dams, and irrigation canals, which had deleterious effects on fish production and small-scale artisanal fisheries in Pakistan (Wescoat 1991).

Indus and inland fisheries resources

Pakistan is blessed with vast freshwater natural resources, including the Indus River and its rich agriculture valley of five river tributaries, the world's largest man-made network of irrigation canals and earth-filled dams and barrages, freshwater lakes, floodplains, waterlogged areas, the Indus delta, and the fast-emerging inland aquaculture ponds. The fisheries sector plays an important role in the national economy of Pakistan as the industry is worth \$1.2 × 10^9 (Akhtar 2010). The fisheries sector contributes 1% to the country's gross domestic product (GDP) and 3% to the agriculture GDP, and provides livelihood for 400,000 fishers while another 600,000 people are involved in ancillary activities (FAO 2013). Unfortunately, fishery management in Pakistan is characterized by limited informa-

Figure 1.—Map showing the Indus River and its tributaries in Pakistan. (Source: World Bank).

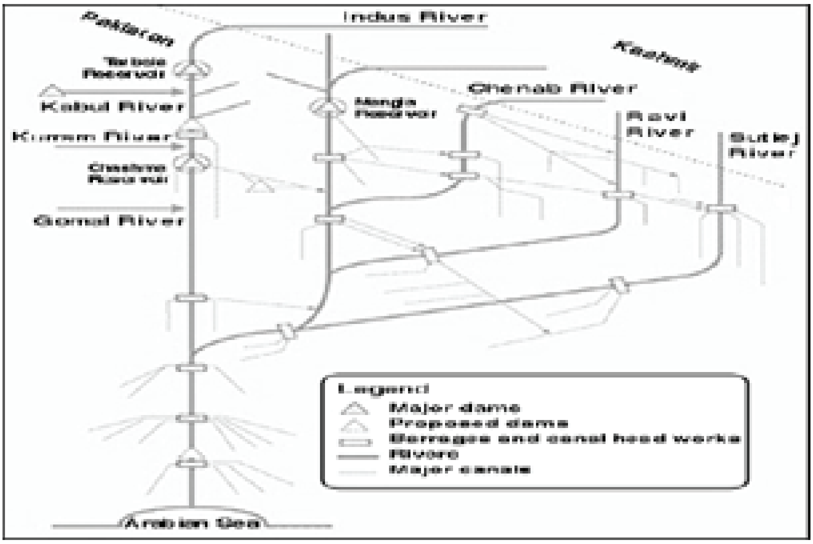

Figure 2.—Schematic diagram of Indus River and tributaries, showing dams, barrage, and the largest irrigation canal network in the world. (Wescoat 1991).

tion about fish stocks as little or no fishery stock assessment is practiced. If such assessment is available, then it can be assumed that before taking any decision regarding rivers, the livelihood of the people will be considered. Dams, water locks, reservoirs, rivers, lakes, and ponds cover an area of approximately 8 million ha possessing varying potential for development of fisheries in the Indus Valley. However, fish catches from rivers and reservoirs account for more than 80% of the total inland fish production (N. Akhtar, paper presented at the National Seminar on Strategic Planning for Fisheries and Aquaculture to Face the Challenges of New Millennium, 2001).

The small-scale artisanal fishing communities of Indus River system use traditional manual fishing gears and small wooden boats. Women are engaged in household and postharvest activities. These communities are facing pressure due to the decline in river water regime, overfishing, aquatic pollution, and human population explosion to 200 million. Moreover, illegal unsustainable fishing, environmental degradation, nonenforcement of fishery regulations, and poor fish marketing infrastructure are contributing the decline in Indus Valley fisheries and threatening the livelihood and food security of artisanal fishers in the Indus Valley, Pakistan. Poverty-driven overfishing by these artisanal fishers using banned nets and practices are driven into a vicious circle of poverty–resource degradation nexus (Khan and Khan 2011). Therefore, a healthy, flowing Indus River and its freshwater natural resources are important for the livelihood and food security of these riverine communities (Irum and Hannan 2012).

The decline in the Indus Valley fisheries and its freshwater natural resources is a result of multiple factors, including overfishing, the decline in river flow due to climate change and drought during the past 50 years, degradation of water quality and river environment resulting from increasing salinity and sea intrusion, and agricultural runoff, as well as the impacts from infrastructure development, urbanization, population explosion, and other anthropogenic activities (Khan 2015). Aquaculture may be an alternate mitigation effort to compensate for the decline in capture fisheries to address the growing threat to livelihood and food security of the poor inland fishing communities. Semi-intensive integrated carp (Chinese and Indian major carps) and Nile Tilapia *Oreochromis niloticus* pond aquaculture has huge promise and potential in the agriculture heartlands of Punjab and Sindh provinces. The village fishers would be interested in raising and catching these fish species for their livelihood. Recently, aquaculture production has shown a rapid surge as fish production increased from 15,000 metric tons in 2000 to more than 140,000 metric tons in 2014 (Figure 3).

Indus valley and inland fishing communities

Inland fish and fisheries play an important role in ensuring food and economic security throughout the world. Freshwater fish are especially important in the developing world, where it provides a critical source of animal protein, essential micronutrients, and livelihoods for local communities. Inland fishing communities and villages are spread along the Indus River and its tributaries, the freshwater lakes (Manchar, Kinjar, and Haleeji in Sindh) and man-made water reservoirs (Tarbela, Chashma, Mangla, and Hub). These poor fishing communities with small-scale fisheries have suffered as natural fish stocks in these inland freshwaters have drastically declined during the past 5 to 6 decades due to deforestation, overfishing, aquatic pollution, and other anthropogenic activities. As a consequence, almost 79% of the people in these fishing communities now live below the poverty line (Mangrove for the Future 2010). The traditional fishing methods were generally considered environmentally friendly as they did not harm the ecosystem. However, the introduction of new mechanized boats and technologies equipped with better nylon nets with finer mesh size are becoming harmful to the sustainability of fish stocks. The poverty–resource degradation nexus is further contributing to this decline in natural resources, thereby reinforcing the poverty of the artisanal fisher (Khan and Khan 2011).

The inland fisheries sector in Pakistan directly supports about 100,000 people for both food and income, and almost 1 million people are indirectly dependent upon these inland freshwater fisheries resources. During the past 20 years, while the fishing fleet had grown by 15%, the fisheries resources have declined drastically and the fish catches have dropped significantly (Wijeratna 2007; Khan and Khan 2011).

Aquatic pollution is also an important reason for the decline of fisheries in Pakistan. The coastal habitats and the aquatic biodiversity are subject to increasing pressures arising from these anthropogenic activities.

Institutional and policy shortcomings are also strong reasons for the decline in freshwater fisheries. Fisheries management measures appear to be confined to a few technical management measures such as closed areas and closed seasons. There is not a comprehensive policy plan for sustainable fisheries development, management, conservation, or restocking of native stocks. Enforcement

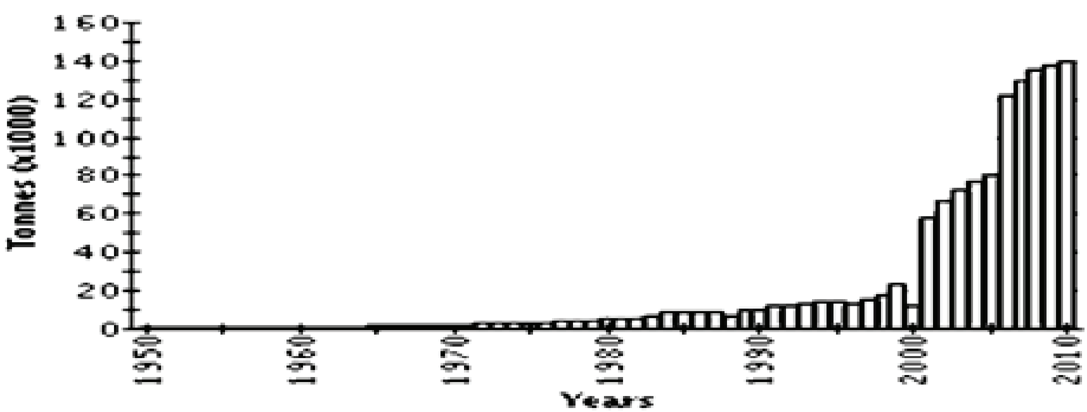

Figure 3.—Showing surge in inland aquaculture production during 2000–2010. (FAO 2014).

of fisheries regulations is a neglected aspect of fisheries management in Pakistan (Wijeratna 2007; Khan and Khan 2011). Due to the shortage of funding, trained human resources, fisheries departments, and other enforcement agencies are ill equipped, ineffective, and unable to implement and enforce the fishing regulations, thereby promoting overharvesting and decline of freshwater fisheries in Pakistan.

The lack of environmental awareness, absence of stock assessments, and nonreplenishment of the depleting fish stocks is further complicating and aggravating the freshwater fisheries in Pakistan. It is encouraging that society and community organizations like the International Union for Conservation of Nature, the World Wide Fund for Nature, Fisher Folk, and educational institutions have successfully raised awareness to protect mangroves of the Indus delta, now declared a Ramsar site. Similarly, the Indus Valley community has been involved in mangrove replantation campaigns to reduce the release of untreated industrial effluents and municipal wastes into the river environment. Therefore, the very survival of freshwater fisheries lies in a change in thought process of the communities, government and nongovernmental agencies, and other stakeholders, along with the strong political will of the government.

Climate change, drought, and inland fisheries

Due to Pakistan's arid to semiarid climate (Figure 4), freshwater is the single most constraining factor for fisheries and aquaculture development. Once abundant, now scarce, Indus Valley freshwater natural resources are predominantly used for agriculture through wasteful flood irrigation techniques. Demand for water is increasing from population growth and industrial and agricultural development. These declining freshwater resources are further threatened by drought and long-term impact of climate change through its effect on temperature, precipitation, and Himalayan glaciers runoff (Wescoat 1991; Xie et al. 2013).

Studies suggest that to minimize the negative impacts of drought and long-term climate change, Pakistan has to immediately take steps like expanding reservoir storage, increasing irrigation efficiency and water use, shifting to drip irrigation, and adaptation of modern water recirculation aquaculture systems for fish production (Wescoat 1991; Ahmed 2002). This can be achieved through development and implementation of policies to monitor the factors discussed above for sustaining fisheries in Pakistan.

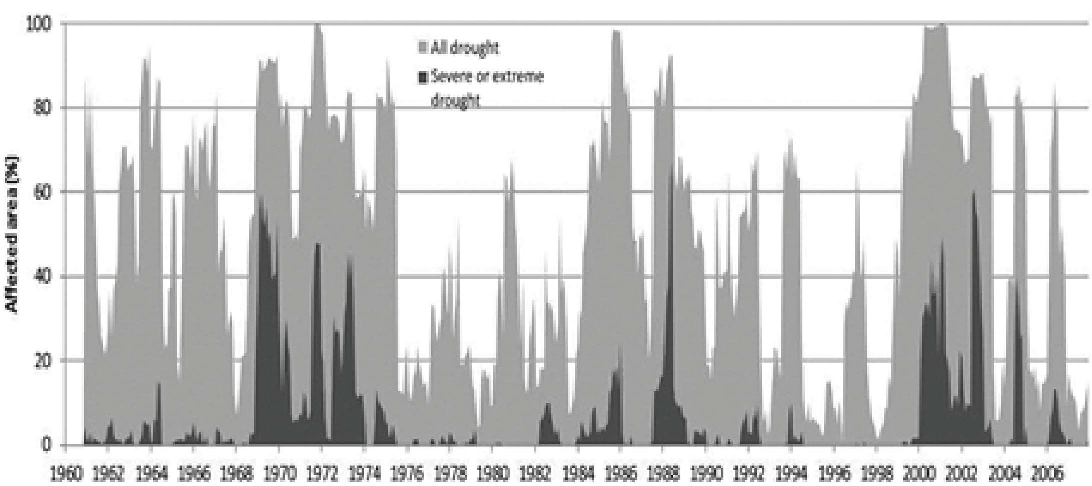

Figure 4.—Showing historical drought cycles and affected areas, Pakistan. The dark, shaded curves represent severe or extreme drought. (Source: Xie et al. 2013).

Inland aquaculture

Global production of farmed fish has more than doubled during the past 30 years. Today, aquaculture is probably the fastest-growing food-producing sector and accounts for almost 50% of the world's food fish and is perceived as having the greatest potential to meet the growing demand for aquatic food (Bostok et al. 2010). In recent years, aquaculture has emerged as one of the fastest-growing and important economical agribusinesses, worldwide (FAO 2015). The aquaculture industry, with an impressive and unprecedented present growth rate of 10–15% compared to agriculture, livestock, poultry, and other food-producing sectors, has grabbed the attention of investors, multinational companies, banks and corporate bodies, and progressive fish culturists, globally.

The global decline in capture fishery has further highlighted the importance of fish production from alternate sources of aquaculture. Today, aquaculture is the most suitable agribusiness for investment due to its broad choice of species diversity, sustainability, consistency, ever-increasing demand, potential for better rate of return, and reduced risks compared to other farming systems like poultry and livestock. Importantly, fish is the only cash crop in Pakistan sold on net cash, while other crops like wheat, rice, and other cereal grains are traditionally sold on loan basis to creditors (FAO 2006; Jha 2010). Therefore, aquaculture has the potential to bring into use the saline and waterlogged, wasted, and marginal agriculture lands, which are otherwise unfit for agricultural crops. Pakistan can augment the production of inland fisheries by promoting early maturing stocks like tilapia and the introduction of protein-rich fish feeds, in addition to traditional pond manuring and fertilization for carp and tilapia production. Fast-growing tilapia may be a better alternate species to grow in Indus Valley brackish waters than traditional fish species.

Conclusions

This paper analyzed the decline in freshwater natural resources and the future of inland fisheries and aquaculture in Pakistan, revealing that freshwater and fisheries resources in the Indus River have declined during the past 5 to 6 decades. Therefore, the sustainability and the historical agricultural prominence of Indus Valley agriculture for centuries is now under severe threat due to a rapid population explosion of 200 million people, the release of untreated industrial and municipal effluents into the Indus River and other freshwaters, increasing salinity, waterlogging, drought and climate change, and poor water management, leading to degraded habitat and unhealthy subsistence and artisanal-level fisheries. Further, the historic river fragmentation due to the Indus Water Treaty of 1960, the construction of large dams, barrages, and a huge network of irrigation canals has not only changed the Indus River ecology, but has brought deleterious effects on fish production and small-scale, riverine, artisanal fishing communities. In conclusion, today, the inland fisheries in Pakistan are threatened by severe environmental degradation, improper fisheries management, indiscriminate overexploitation of stocks, illegal fishing practices, agricultural runoff, population explosion, and other anthropogenic activities. Perhaps aquaculture can provide a new and innovative alternate to declining inland fishery in Pakistan and the paradise lost.

Policy Recommendations:

The following policy recommendations are suggested:

1. Inland fisheries resources should be exploited in a sustainable manner to provide livelihood to the poor, vulnerable artisanal fishing communities; fisheries rehabilitation projects should be launched in the province of Punjab and Sindh to promote fish farming on millions of hectares of waterlogged and wasted agriculture lands.
2. Capacity building and provision of alternate livelihoods to traditional artisanal fishing communities;
3. Capacity building of provincial fishery institutions for improved legislation, en-

forcement, and regulation of inland fisheries, and reporting the decisions to water management authorities to act upon and help them;
4. Protection of critical fisheries habitat, wetlands, fish sanctuaries, parks, mangroves, and riverine forests by running an awareness campaign to water-reliant sectors, such as industries and municipalities;
5. Promotion of fish culture on millions of hectares of waterlogged land;
6. Breaking of poverty–resource degradation nexus through the launching of a formal credit system for poor fishing communities;
7. Replacement of a centuries-old traditional fish marketing system with modern sanitary and phytosanitary-driven quality-control marketing;
8. Launching of an awareness campaign for conservation of aquatic biodiversity, fisheries, and freshwater resources;
9. Climate change risk and vulnerability assessment and management;
10. Mainstreaming climate change into development planning;
11. Holistic ecosystem-based futuristic strategic planning and conflict resolution at the River Indus basin scale by educating the fishers about the host and prey concept; and
12. Restoration of depleted fish stocks resistant to salinity, waterlogging, drought, and nutrients through establishment of fish hatcheries along the river system for fish-stock replenishment.

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Drivers of Caribbean Freshwater Ecosystems and Fisheries

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Abstract.—Freshwater tropical island environments support a variety of fishes that provide cultural, economic, and ecological services for humans but receive limited scientific, conservation, and public attention. Puerto Rico is a Caribbean tropical island that may serve as a model to illustrate the interactions between humans and natural resources in such complex ecosystems. The native freshwater fish assemblage of Puerto Rico is distinct from mainland assemblages in that the assemblage is not diverse, all species are diadromous, and they may be exploited at multiple life stages (e.g., postlarva, juvenile, adult). Primary large-scale drivers of recent water-use policy include economic growth, human population density, and urbanization, with climate change as an overarching influence. Watershed and riparian land use, water quality, river flow and instream physical habitat, river habitat connectivity, exotic species, and aquatic resource exploitation are important proximate factors affecting the ecosystem and fisheries. Research on ecological processes and components of the stream and river fish assemblages has expanded the knowledge base in the past decade with the goal of providing critical information for guiding the conservation and management of the lotic resource to optimize ecosystem function and services. The greatest challenge facing Caribbean island society is developing policies that balance the needs for human water use and associated activities with maintaining aquatic biodiversity, ecological integrity and services, and sustainable fisheries. Achieving this goal will require broad cooperation and sustained commitment among public officials, agency administrators, biologists, and the public toward effective resource management.

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Environmental and Societal Setting of Caribbean Island Ecosystems

Tropical islands are important ecosystems that harbor unique and diverse terrestrial and aquatic faunas. The marine fishes and fisheries of tropical islands typically receive substantial scientific, conservation, and public attention, but island freshwater environments also support a variety of fishes that provide cultural, economic, and ecological services for humans. The fish assemblages in such freshwaters vary widely in diversity, life history patterns, and level of human interactions. The objectives of this contribution are to describe the components of Puerto Rico inland fisheries and their services as a Caribbean island case study, identify large-scale drivers and proximate factors that influence water-use and fisheries policy and management, summarize research to inform decisions, and provide conclusions and a future outlook.

Puerto Rico is a moderately sized Caribbean tropical island that may serve as a model to illustrate interactions between humans and natural resources in such complex communities (Figure 1). The native freshwater fish assemblage of Puerto Rico is distinct from mainland assemblages but typical of oceanic tropical islands in that it is not diverse, all species are diadromous, and they are exploited at multiple life stages. Puerto Rico is an ideal setting to study human influences on aquatic resources because of an extremely dense human population and the associated demands for water and activities that impact freshwater and marine ecosystems and fisheries (Ramírez et al. 2012). We have studied various ecological processes and components of the stream and river fish assemblages of Puerto Rico during the past decade with the goal of providing critical information for guiding the conservation and management of the lotic resource. Our findings may serve to identify and elucidate aquatic ecological functions, services, and drivers of freshwater fisheries to better inform natural resource agencies in strategic planning and implementation of such plans.

The Biota

The Caribbean regional fish fauna is notably diverse, but the freshwater island fish assemblages are much less so. The freshwater fish fauna of Puerto Rico includes a moderately diverse assemblage of 14 orders, 29 families, and 82 species (Kwak et al. 2007; Neal et al. 2009) of which only 26 are obligate freshwater species. These include at least 37 predominantly marine or estuarine fish species of 18 families (Neal et al. 2009). Among the freshwater fish species (Table 1), only 7–10 species are native, representing four families (the Sirajo Goby *Sicydium plumieri* has been split into four distinct *Sicydium* species (Watson 2000); it is not clear which are present in Puerto Rico). These native freshwater fishes occur throughout the Caribbean (Froese and Pauly 2015) and are of primary conservation and management concern at local and regional scales.

Native diadromous fishes

All of the native freshwater fishes of Puerto Rico are diadromous and require marine–freshwater connectivity to complete their life cycle. Among the native freshwater fishes, only one, American Eel, is catadromous, and the remaining species are amphidromous (Figure 2), including gobies (Gobiidae, up to five species), sleepers (Eleotridae, three species), and mullet (Mugilidae, one species) (Table 1; Kwak et al. 2007; Neal et al. 2009). Amphidromy is a unique life history in which adults live and spawn in streams, larvae hatch and drift downstream to the sea, pelagic larvae develop and grow in estuaries or the ocean, and postlarvae recruit to rivers and migrate upstream (Figure 2; McDowall 1999; Keith 2003; Keith et al. 2008). Amphidromy is common among native fish assemblages of tropical and subtropical islands of volcanic origin (Keith 2003; March et al. 2003).

Exotic freshwater fishes

The freshwater fish fauna of Puerto Rico is dominated by exotic fishes (Table 1). Of the 45 primarily freshwater species on the island, 38 are introduced exotic species (Kwak et al. 2007; Neal et al. 2009). In fact, the number of

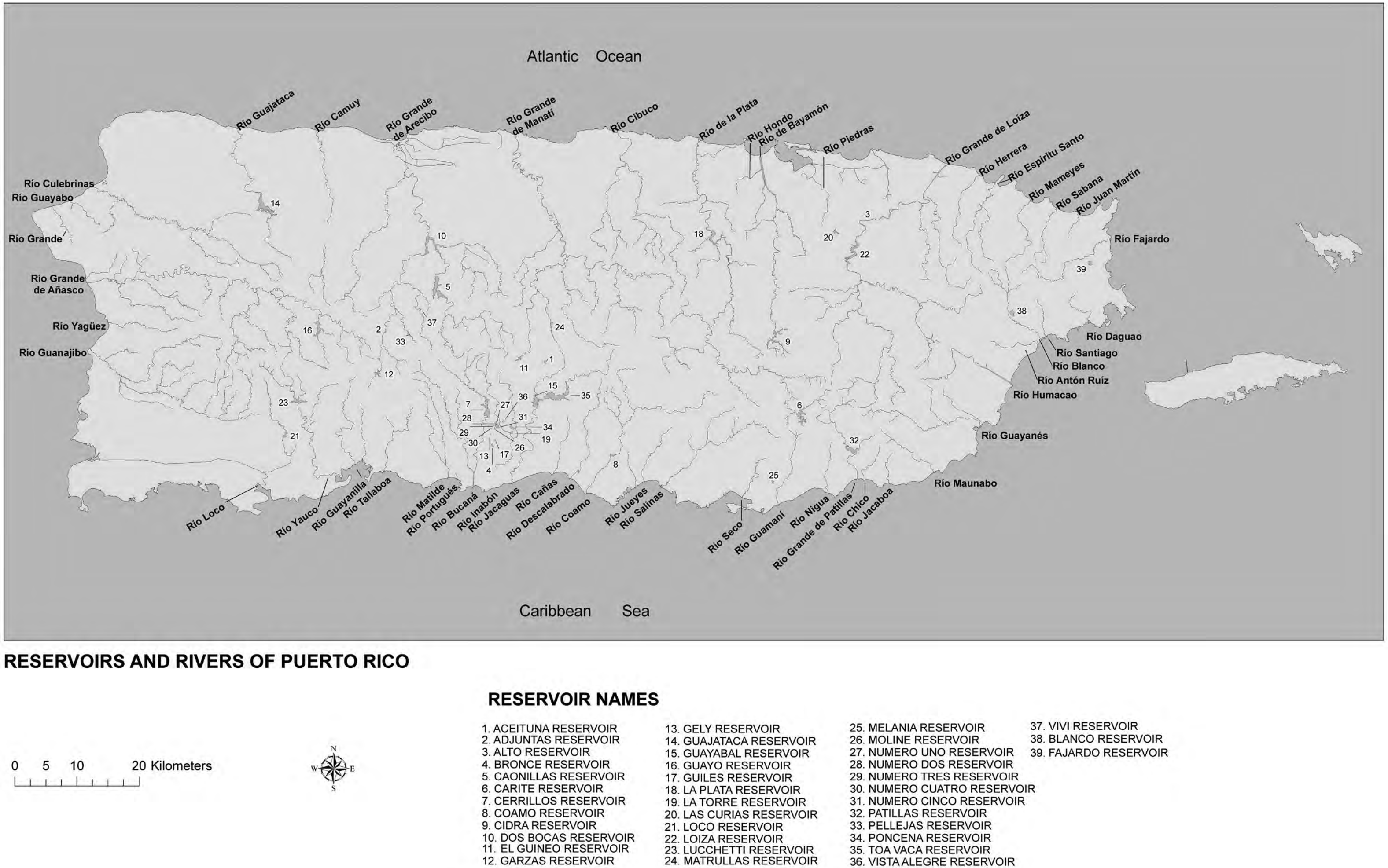

Figure 1.—Map of the surface freshwater resources in Puerto Rico, including primary river systems and reservoirs. Map modified and reprinted with permission of the Puerto Rico Department of Natural and Environmental Resources.

Table 1.—Freshwater fish species found in the streams, rivers, and reservoirs of Puerto Rico. Additional freshwater fish species are rarely collected in these water bodies, and marine species frequently occur in lowland river reaches. *Sicydium plumieri* has been split into four *Sicydium* species (*S. buscki*, *S. gilberti*, *S. plumieri*, and *S. punctatum*; Watson 2000); it is not yet clear which are present in Puerto Rico.

Family	Species	Common name (English)	Common name (Spanish vernacular)	Origin	Migratory life history	Status
Anguillidae	*Anguilla rostrata*	American Eel	Anguila	Native	Catadromous	Widespread
Centrarchidae	*Lepomis auritus*	Redbreast Sunfish	Chopa Pechicolorada	Introduced	Resident	Widespread
	L. macrochirus	Bluegill	Chopa Criolla	Introduced	Resident	Widespread
	L. microlophus	Redear Sunfish	Chopa Caracolera	Introduced	Resident	Widespread
	Micropterus chattahoochae	Chattahoochee Bass		Introduced	Resident	Maricao River
	M. salmoides	Largemouth Bass	Lobina	Introduced	Resident	Widespread
Characiformes	*Myleus rubripinnis*	Redhook Silver Dollar	Pacú	Introduced	Resident	Cerrillos Reservoir
Cichlidae	*Amatitlania nigrofasciata*	Convict Cichlid	Cíclido Zebra	Introduced	Resident	Expanding
	Amphilophus labiatus	Red Devil Cichlid	Diablo Rojo	Introduced	Resident	Expanding
	A. citrinellus	Midas Cichlid	Diablito Rojo	Introduced	Resident	Expanding
	Astronotus ocellatus	Oscar	Oscar	Introduced	Resident	Loíza and La Plata reservoirs
	Cichla ocellaris	Butterfly Peacock Bass	Tucunaré	Introduced	Resident	Widespread
	Cichlasoma cyanoguttatum	Rio Grande Cichlid		Introduced	Resident	Rare
	Parachromis managuensis	Jaguar Guapote	Jaguar Guapote	Introduced	Resident	Expanding
	Oreochromis aureus	Blue Tilapia	Tilapia Azul	Introduced	Resident	Widespread
	O. mossambicus	Mozambique Tilapia	Tilapia Mosambica	Introduced	Resident	Widespread
	Thorichthys meeki	Firemouth	Boca de Fuego	Introduced	Resident	Widespread
	Tilapia rendalli	Redbreast Tilapia	Tilapia Pechiroja	Introduced	Resident	Widespread
	Vieja synspila	Redhead Cichlid	Cabeza de Fuego	Introduced	Resident	Expanding
Clupeidae	*Dorosoma petenense*	Threadfin Shad	Sardina	Introduced	Resident	Widespread
Cyprinidae	*Carassius auratus*	Goldfish	Goldfish	Introduced	Resident	Rare
	Puntius conchonius	Rosy Barb	Mino Rosado	Introduced	Resident	Locally abundant
Eleotridae	*Dormitator maculatus*	Fat Sleeper	Mapiro	Native	Amphidromous	Widespread
	Eleotris perniger	Smallscaled Spinycheek Sleeper	Morón	Native	Amphidromous	Widespread
	Gobiomorus dormitor	Bigmouth Sleeper	Guavina	Native	Amphidromous	Widespread
Gobiidae	*Awaous banana*	River Goby	Saga	Native	Amphidromous	Widespread
	Sicydium plumieri	Sirajo Goby	Olivo	Native	Amphidromous	Widespread
Gyrinocheilidae	*Gyrinocheilus aymonieri*	Chinese Algae-eater		Introduced	Resident	Rare

Table 1.—Continued.

Family	Species	Common name (English)	Common name (Spanish vernacular)	Origin	Migratory life history	Status
Ictaluridae	*Ameiurus nebulosus*	Brown Bullhead	Torito Barbudo	Introduced	Resident	Widespread
	A. catus	White Catfish	Barbudo Blanco	Introduced	Resident	Widespread
	Ictalurus punctatus	Channel Catfish	Barbudo de Canal	Introduced	Resident	Widespread
Loricariidae	*Pterygoplichthys multiradiatus*	Sailfin Catfish	Pleco	Introduced	Resident	Widespread
Mugilidae	*Agonostomus monticola*	Mountain Mullet	Dajao	Native	Amphidromous	Widespread
Pangasiidae	*Pangasianodon hypophthalmus*	Basa Catfish	Basa	Introduced	Resident	Loiza Reservoir
Poeciliidae	*Gambusia affinis*	Western Mosquitofish	Pez Mosquito	Introduced	Resident	Widespread
	Poecilia reticulata	Guppy	Gupi	Introduced	Resident	Locally abundant
	Xiphophorus helleri	Green Swordtail	Cola de Espada	Introduced	Resident	Locally abundant
	X. maculatus	Southern Platyfish	Platy	Introduced	Resident	Locally abundant

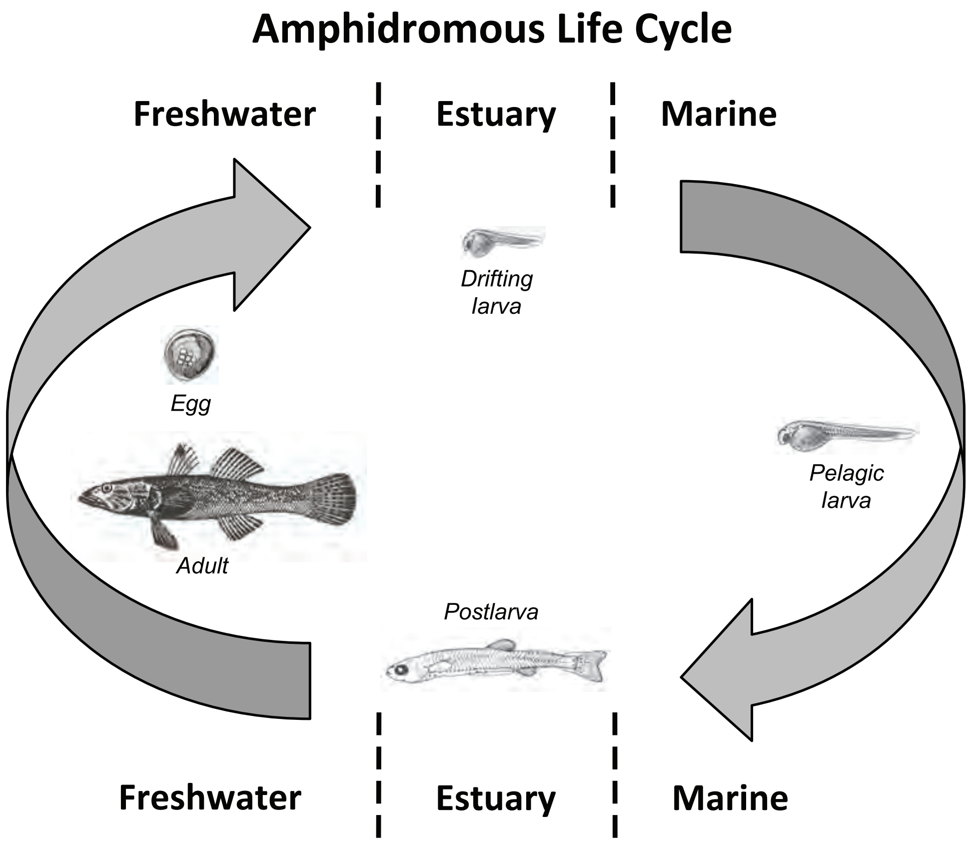

Figure 2.—Conceptual diagram of the amphidromous fish life cycle, in which adults live and spawn in streams, larvae hatch and drift downstream to the sea, pelagic larvae develop and grow in estuaries or the ocean, and postlarvae recruit to rivers.

freshwater exotic fish species and ratio of exotic-to-native freshwater fishes in Puerto Rico is among the highest globally for island faunas (Erdman 1984; Vitousek et al. 1997). Exotic fishes were introduced to Puerto Rico through intentional stockings, escapes from the aquaculture industry, aquarium releases, and anglers. Recent introductions include the Sailfin Catfish, Chinese Algae-eater (also known as Siamese Algae-eater), and an expanding list of species from the families Poeciliidae and Cichlidae (Table 1; Bunkley-Williams et al. 1994; Kwak et al. 2007; Neal et al. 2009). Some of these exotic fishes provide recreational fisheries and human food sources in areas where native fish cannot survive (e.g., reservoir habitat), but the majority are invasive species that are detrimental to native fishes and habitat (Erdman 1984; Fuller et al. 1999; PRDNER 2008). Exotic species may be harmful to native fish by direct (e.g., predation, aggressive behavior) or indirect (e.g., habitat destruction, competition) processes and can function as vectors of pathogens and parasites (Bunkley-Williams and Williams 1994; Font and Tate 1994; Brasher 2003). The impact of exotic introductions to Caribbean native species and the freshwater ecosystem is complex, is not well understood, and warrants additional research.

Freshwater fisheries

Freshwater recreational fisheries exist in stream, river, and reservoir environments in Puerto Rico. Recreational and subsistence fisheries for freshwater native fishes exist for two primary life stages—adult fish in rivers, and postlarval stages at river mouths as the postlarvae migrate upstream from marine to riverine environments. Our personal observations confirm that fisheries for adult native fishes can be popular in riverine environments, especially in lowland reaches, but fishing effort and exploitation rates are largely unknown. The target species in streams and rivers may be variable and span both freshwater and marine species, including Bigmouth Sleeper, Mountain Mullet, Tarpon *Megalops atlanticus*, and multiple species of snook *Centropomus* spp. A single survey in 2014 at the Arecibo River mouth and estuary in northwest Puerto Rico suggested that effort, catch, and harvest may be concentrated spatially to the freshwater–marine interface and temporally coinciding with mass migrations of amphidromous postlarval fish (authors' unpublished data).

Postlarvae of native amphidromous fishes are individually small (12–30 mm) but can be very dense and numerous during periodic migrations that support important artisanal fisheries. Such fisheries exist extensively in tropical areas of volcanic habitat in the Pacific, Caribbean, Central America, and Indian Ocean, but many are in decline (Bell 1999). Postlarvae harvest rates in these locations can be substantial (up to 20,000 metric tons/year), even though they are seasonal and follow monthly lunar periodicity (Bell 1999; Castellanos-Galindo et al. 2011; authors' unpublished data). Estimates of postlarval exploitation are rare in the literature due to the local, informal, and largely unregulated nature of the fisheries. The species supporting these fisheries are typically assumed to be Sicydiine gobies, but in Puerto Rico we have found that the catch may include species of Eleotridae and the River Goby, in addition to Sicydiine species, that are aggregately referred to as cetí. In Puerto Rico, the gear used for cetí fishing is small sections of fine-mesh mosquito netting, fished actively by 1–3 persons along sandy banks at mouths of rivers with large basin areas.

Recreational fisheries are locally popular in Puerto Rico reservoirs and are primarily managed for exotic fish species by the Puerto Rico Department of Natural and Environmental Resources (Neal et al. 2004, 2008, 2009). Facilities (e.g., public shoreline access, boat ramps) are well developed at a few large reservoirs, and competitive angling tournaments occur on those systems. Target species for angling are Largemouth Bass, sunfishes *Lepomis* spp., Butterfly Peacock Bass, tilapias (*Oreochromis* spp. and *Tilapia* spp.), Jaguar Guapote, and Channel Catfish. The policy to manage reservoir fisheries for exotic species stems from the lack of available habitat in those systems for native fishes (Neal et al. 2004). In one reservoir (Carite, Figure 1), a landlocked population of native Bigmouth Sleeper supports a recreational fishery (Bacheler et al. 2004), but the species is absent from all other reservoirs, and efforts to culture the fish in captivity have so far been unsuccessful (Harris et al. 2011).

Artisanal shellfish fisheries also exist in lower river reaches and estuaries of Puerto Rico. Hand-net fishing for *Atya* or *Macrobrachium* shrimp, the endemic freshwater Puerto Rican crab *Epilobocera sinuatifrons*, the invasive Australian red claw crayfish *Cherax quadricarinatus* (an accidental, unauthorized introduction), or estuarine shellfish species is common. In addition to providing a local human food source, crustaceans in lotic and estuarine habitats can reach high densities and biomasses and form critical components and trophic linkages of the riverine food web (Benstead et al. 2000; Kwak et al. 2007).

The Environment

Puerto Rico is about 175 × 62 km at its longest dimensions (8,870 km^2 total) and is bisected by an east–west mountain chain (La Cordillera Central) from which many of the island's rivers originate (Figure 1). A prominent trait of Puerto Rico is its high human population density. The capital city of San Juan and other major urban centers in the coastal plain support much of the nearly 99% urban population of approximately 3.6 million, with a corresponding density of 406 people/km^2 (CIA 2014).

Aquatic ecosystems

The topography of Puerto Rico forms more than 50 river systems that originate at mountain elevations and flow through foothills and coastal plain regions before draining into the Caribbean Sea or Atlantic Ocean (Figure 1). This pattern of river network development is ideal for the study of lotic ecological processes and human influences in a reduced spatial scale, relative to much larger mainland river basins. Additionally, since Puerto Rico has already undergone intense urbanization—a process that is underway on a global scale in the tropics—studies of how aquatic systems respond to anthropogenic drivers there may serve to predict future changes in developing nations (Ramírez et al. 2012). Puerto Rico rivers are typical of Antillean systems, with high gradients and coarse rocky substrate materials with a resulting flashy, flood-dominated hydrology associated with high rainfall (averaging nearly 5 m annually, Lugo et al. 2012).

The rivers of Puerto Rico are impounded by 27 high dams (>20 m) that form large reservoirs and hundreds of smaller low-head dams, road crossings, and other artificial instream barriers (Figure 1; Cooney and Kwak 2013). Thirteen of these reservoirs exceed 100 ha in area, and many are reduced in area by sedimentation from upstream erosion (Neal et al. 2009). These variable environments are generally regulated by water-level management for flood control and hydropower generation, rather than seasonal rainfall, recreational use, fisheries management, or downstream ecological flows. Two coastal lagoons are the only natural lentic water bodies on the island, and they are intensively impacted by human alteration and activities.

The Human Population

The people of Caribbean islands have a long and rich history of interaction with aquatic natural resources. Freshwater fish are valued and prominently featured for their natural and cultural heritage values. The earliest known Caribbean fishers were the Taíno, pre-Columbian inhabitants of the West Indies (Lovén, 2010). They fished the rivers using many innovative techniques, including hook and line, spears and arrows, nets, baskets, weirs, and hand, including the use of natural plant poisons to harvest freshwater fish. The Taíno were farmers, hunters, and fishers, and their survival and culture relied on island natural resources. A remnant of Taíno culture and its relationship with fisheries resources remains today in local names for native Caribbean fishes and postlarvae (e.g., cetí, Guavina, and Dajao; Table 1) that originated in the Taíno language (De las Casas 1951).

Under Spanish rule in the 19th century, fishing rights at productive areas near river mouths in Puerto Rico were sold to a small number of fishers (Wright and Folsom 2002). After the U.S. Government assumed control of Puerto Rico in 1898, exclusive fishing rights were abolished, and small commercial fisheries developed (Wilcox 1903; Wright and Folsom 2002). Commercial fishing was conducted at the river mouths by seine, cast net, pot gears, and hook and line, and fishing up the rivers was primarily subsistence fishing by families.

Today, the freshwater fisheries remain an important cultural resource and component of the island natural heritage. This was confirmed in a survey of Puerto Rico households that indicated that although the public's knowledge about specific river systems was limited, they would be willing to pay to maintain ecological integrity of Puerto Rico rivers (González-Cabán and Loomis 1997). Freshwater anglers share information via social media, and nongovernmental conservation organizations are active in policy and management of aquatic natural resources.

The dense human population and limited freshwater fishery resources require effective regulation and enforcement to avoid overexploitation, which presents a major challenge. For decades, Puerto Rico fisheries were regulated by a law developed in 1936 (Public Law 83 of 13 May 1936; Matos-Caraballo 2009), until 1998 when legislation was enacted mandating the Puerto Rico Department of Natural and Environmental Resources to develop contemporary fishing regulations (Public Law 278 of 29 November 1998). Freshwater fishing regulations developed by the Puerto Rico Department of Natural and Environmental Resources limit the allowable gears, creel limits, and associated rules, and they are enforced by the Puerto Rico Natural Resources Ranger Corps. The Puerto Rico Department of Natural and Environmental Resources also operates the Maricao Fish Hatchery to culture freshwater sport fish (Largemouth Bass and sunfishes *Lepomis* spp.) for stocking reservoirs. Currently, there is no inland commercial fishery and plans are being finalized to initiate a recreational fishing license for fresh and marine waters, but none is required at this time.

Ecosystem and Fisheries Services and Drivers

As with most fisheries and ecosystems in developed and undeveloped nations, the ultimate driver regulating system integrity and fisheries productivity is the human population—and this is especially true in Puerto Rico with a dense, urban population. The Caribbean region is a particularly densely populated area and Puerto Rico is among the most populated islands (United Nations 2014). The Puerto Rico population has fluctuated around just under 4 million people for the past decade, peaking in 2009 and decreasing steadily since. With conflicting uses of natural resources, aquatic ecosystem and fisheries management is a balance of tradeoffs between meeting needs of human uses and maintaining the integrity of ecosystems and sustainability of fisheries.

Human water resource needs for municipal water, agriculture, power generation, and flood control are intensive for Puerto Rico and most island communities. Native fish and fisheries require suitable quantities and quality of habitat to flourish and sustain fishery services, but human activities instream and on the watershed can degrade habitat quality and restrict its availability. Thus, human activities that alter watershed and riparian land use, water quality, river flow, and instream physical habitat; fragment river habitat; introduce exotic species; and overexploit aquatic resources are primary factors affecting the ecological integrity of freshwater systems and the ecological services that they may provide to humans (Neal et al. 2009; Kwak and Freeman 2010; Engman and Ramírez 2012).

Research to identify and elucidate ecological influences and drivers

Research and a strong knowledge base can inform and guide conservation strategies and management actions to minimize and mitigate detrimental consequences of human activities on aquatic ecosystems. Collaborative research among the authors and cooperating universities and agencies has expanded the knowledge base substantially for river ecosystems and fisheries in Puerto Rico during the past decade (Kwak et al. 2007, 2013).

Modeling habitat and distributional patterns.—An initial research step was to evaluate properties of fish sampling gears and develop a standard protocol to assess fish assemblages (Kwak et al. 2007). We determined that a three-pass removal estimator based on electrofishing catch was the most efficient and least biased among the models examined to estimate density and biomass for each species within the assemblage. We followed that protocol to sample the fish assemblages at 118 sites spanning elevations up to 700 m, covering all river basins. The catch included 28 species from 16 families with fish density ranging up to 83,000 fish/ha and biomass up to 622 kg/ha, and assemblage indices identified patterns in native and exotic fish distributions. We found that fish assemblages upstream of a high dam and the associated reservoir differed from those assemblages without a downstream reservoir, and native fish were tolerant to watershed and riparian urbanization. Thus, the use of fish assemblages alone may not serve as suitable indicators of ecological integrity (Kwak et al. 2013). We also developed fish condition index relationships for native Caribbean amphidromous fish species (Cooney and Kwak 2010). Hierarchical models to describe fish assemblage patterns from instream habitat parameters and landscape attributes revealed that basin-level influences appear to structure fish assemblages more than site- or reach-scale factors. Thereby, the fishery resource was described and quantified, assessment indices developed and evaluated, and the appropriate management scale was identified.

Diadromous Caribbean fishes depend on habitat connectivity between freshwater and marine habitats, and dams and instream barriers block fish migrations required to complete their life cycle and can lead to local extirpations (Figure 3; Holmquist et al. 1998; Greathouse et al. 2006; Cooney and Kwak 2013). In Puerto Rico, we identified and surveyed 335 artificial barriers that hinder fish migration to 74.5% of the upstream habitat (Cooney and Kwak 2013). By integrating fish surveys and the occurrence of dam and instream barriers into distributional models, we were able to quantify specific artificial barrier characteristics that restricted migration and occurrence to each fish species and assemblage component (Figure 3). Barriers 4 m high extirpate nongoby native species, and no native species occur upstream of dams 32 m high. These findings quantify the extent of habitat loss and identify specific traits of critical influences on ecosystem connectivity and fish habitat availability that may be manipulated in management.

Water quality is a critical factor affecting freshwater ecosystems and may restrict water resource use and fish distributions. The freshwaters of Puerto Rico have received substantial sediment, chemical, and nutrient pollution from a variety of sources (Hazen 1988; Hunter and Arbona 1995; Warne et al. 2005). We quantified occurrences and patterns of aquatic contaminants (organic and metals) as related to trophic relationships and watershed land-use characteristics of Puerto Rico streams (Buttermore 2011). Overall, the streams were not severely polluted, with the exception of elevated concentrations of polychlorinated biphenyls and mercury in several fish species from agricultural and urban streams. Contaminant concentrations were more closely correlated with consumer lipid content than with trophic level. Bigmouth Sleeper may be the most suitable fish for human consumption with low levels of organic contaminants, but mercury accumulation was elevated in some instances. These findings provide public health and natural resource agencies the scientific information required to guide ecosystem and fisheries management and human health risk assessment.

Amphidromy and recruitment.—All but one of the Puerto Rico native freshwater fishes are amphidromous (Figure 2), and their life history and ecology are generally poorly understood

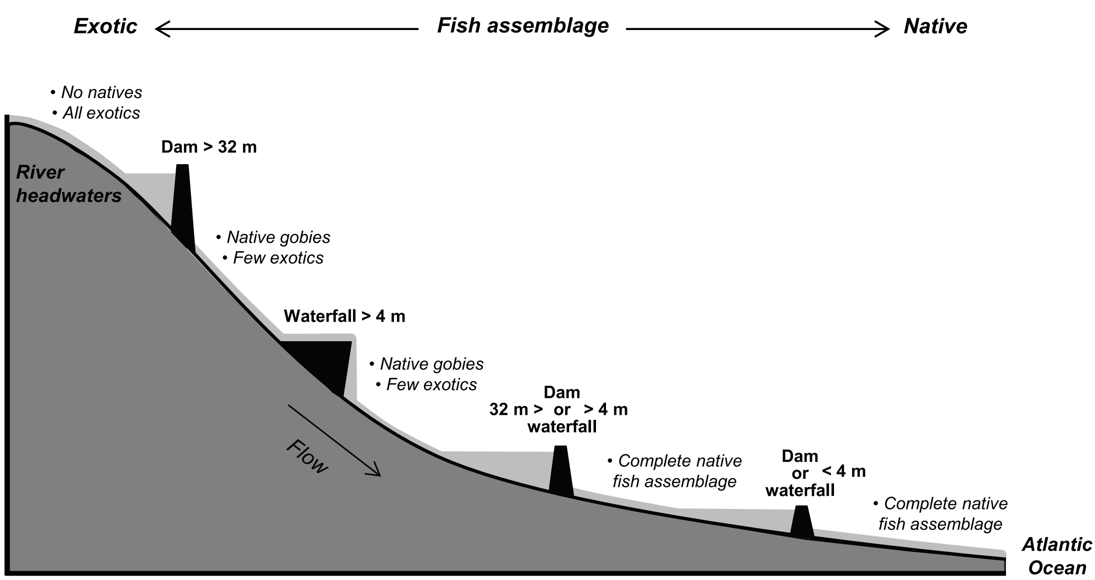

Figure 3.—Instream dams and other artificial barriers block the migration and limit the distribution of native Caribbean diadromous fish species at varying heights, forming a continuum in the fish assemblage from native to exotic species proceeding upstream. (From Cooney and Kwak 2013).

(McDowall 1988). We conducted intensive fish-tagging studies and extensive otolith microchemistry analyses and a survey of reproductive characteristics to elucidate patterns and dynamics in the amphidromous life history of native Puerto Rico fishes (Smith 2013; Smith and Kwak 2014a, 2014b). Integrated results of fish tagging and otolith microchemistry confirmed amphidromy as the predominant life history, with some degree of plasticity. We defined the spawning period for native amphidromous fishes from late spring through early fall and found that fish were capable of maturation at small sizes. Life-history parameters indicated that amphidromous fishes followed an intermediate periodic-opportunistic life-history strategy, with the postlarval migration period during the third-quarter moon phase. These findings have identified that critical seasonal periods and habitats for management of specific life-history functions (e.g., migration, reproduction) indicate that amphidromous fish assemblages are robust to adult exploitation rates ranging between low to moderate levels, but additional data are needed to assess sustainable levels of postlarvae exploitation, and that they can be successfully managed by maintaining abiotic conditions that structure populations and communities.

Conclusions, Challenges, and the Future

The freshwater lotic ecosystems of Puerto Rico provide many human benefits, and water resource needs for municipal water, agriculture, power generation, and flood control may conflict with ecological services, including fisheries. The primary large-scale drivers of recent water-use policy in Puerto Rico are economic growth, population density, and urbanization, associated with a shift from crop- and pasture-based agriculture to industry since the 1950s (Van Beusekom et al. 2014). However, climate change is a broad-scale, growing influence on policy and management decisions. A suite of tradeoffs and synergies has resulted from past water-use decisions. For example, decisions to construct high dams and associated reservoirs for municipal water, agriculture, power generation, and flood control are detrimental to upstream and downstream ecological integrity and associated stream services, but reservoir fisheries for exotic species provide recreational and economic benefits (Greathouse et al. 2006; Neal et al. 2008). Common ground between government agencies and fisheries stakeholders has proven difficult to achieve in communications associated with policy, fishing regulations, and management. This remains a key obstacle to attaining sustainable water use and fisheries policies. Identification and consideration of these conflicts, tradeoffs, and synergies are critical challenges in future water use planning and policy decisions.

Climate change is an overarching influence that has impacted Puerto Rico water resources in the past and is an important driver to be considered in future water use planning and policy. Precipitation and river flow are projected to decrease in all regions of the island, exacerbating the current water management of this limited resource (Henareh Khalyani et al. 2016; Van Beusekom et al., in press). Total streamflow is projected to decrease 39–88% from historical amounts from the 1960s to the 2090s, and projected streamflow is shown to decrease substantially below projected withdrawals at locations critical to human water supply (Van Beusekom et al., in press). If water allocation policy continues to favor human uses over ecological needs, the impact on stream services and fisheries will worsen.

We identified watershed and riparian land use, water quality, river flow and instream physical habitat, river habitat connectivity, exotic species, and aquatic resource exploitation as proximate controlling factors of the ecosystem and fisheries. We have conducted research to inform and guide conservation and management activities to optimize the function of these factors within the bounds of human needs. These new research findings provide the knowledge base and tools that may be applied in strategic planning and management.

This knowledge base and tool set continue to grow and are available to conservation and management agencies and organizations. Human water use, however, is also expected to grow in future years, and the value of maintaining ecological integrity of aquatic ecosystems is becoming increasingly recognized and incorporated into Caribbean water resource planning (González-Cabán and Loomis 1997; March et al. 2003; PRDNER 2008). Thus, the greatest challenge facing Caribbean island society is developing policies that effectively balance the needs for human water use and associated activities with maintaining aquatic biodiversity, ecological integrity and services, and sustainable fisheries. Achieving this goal will require broad cooperation and sustained commitment among public officials, agency administrators, biologists, and the public toward effective resource management.

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Improving Rural Livelihoods through Sustainable Integrated Fish: Crop Production in Limpopo Province, South Africa

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Abstract.—More than 70% of Limpopo Province's inhabitants reside in rural areas where high rates of poverty and malnutrition prevail. The province has constructed 171 irrigation dams for water storage. These freshwater resources were only used as water storage for irrigation instead of multipurpose uses such as fish production, recreation, and drinking water to address socioeconomic challenges.

The objective of the study was to develop a sustainable integrated fish-crop production system to address food insecurity, create jobs, reduce poverty, and generate income.

The study was conducted in 2012 with the rehabilitation of a deserted water storage dam with a total surface area of 6,000 m^2. The dam reservoir was divided into four fish ponds. Fish were stocked into these ponds with the result that carp averaged 1.2 kg, tilapia 0.5 kg, and catfish 1.5 kg after a period of 4 months

The production system yielded about 55 metric tons of fish per annum worth US$4,396.24 and created 110 temporary and 48 permanent jobs.

Introduction

Aquaculture can become a good way to alleviate poverty in Limpopo Province as the abundant freshwater supply could be used to raise fish. Lots of poor people in Limpopo Province could benefit from raising fish in their irrigation waters to provide food and cheap protein. Limpopo Province has about 90% of the population residing in rural areas, and 47.5% are younger than 15 years old. The province had the highest population growth of 3.9% per annum compared to other provinces in South Africa (De Cock et al. 2013). The people in the rural areas of Limpopo Province live below the poverty line with lower access to nutritious food and basic needs.

Limpopo Province has two major tributaries, namely the Olifants and Limpopo rivers, with a number of storage dams built for irrigation and provision of drinking water. Limpopo has great aquaculture potential due to the abundant water supply created by the dams. By contrast, other provinces such as Mpumalanga, North West, and KwaZulu-Natal do not have the same aquaculture potential, due to inadequate water supply.

Limpopo farmers have been using flood irrigation systems since 1997 to irrigate vegetables, maize, potatoes, cotton, and wheat crops. The water from large water bodies was directed through cement canals to the balancing or storage dams and later directed into the fields through furrow or flood irrigation system. Farmers were assisted by the Limpopo Department of Agriculture and other government agencies to register as legal entities called cooperatives to operate in a group and share the dividends equally.

In 2000, the change to a floppy sprinkler irrigation system led to abandonment of the balancing dams at most of the irrigation sites in Limpopo Province. During 2012, the Depart-

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ment of Agriculture facilitated the rehabilitation of the deserted balancing dam at a cost of US$19,400.00 in Limpopo Province. The priority for the rehabilitation of the dam was to promote aquaculture as an opportunity to address socioeconomic challenges.

Currently, the province has abundant water resources, including 171 agricultural irrigation schemes where people grow crops and irrigate with water from storage dams. Communities residing in these areas are poor and concentrate more on crop production at the subsistence farming level. Limpopo Province still needs to address the issues of food insecurity, malnutrition, unemployment, and other social and economic challenges (De Cock et al. 2013). An additional way to reduce poverty and improve rural livelihoods is to encourage optimum utilization of available water and fish resources in a sustainable manner.

Aquaculture is a beneficial and sustainable use of water as a medium in which to rear organisms (Rouhani and Britz 2004). Freshwater aquaculture can contribute to economic development and food security in rural areas of South Africa (Rouhani and Britz 2004). The opportunity lies in the integration of aquaculture into existing agricultural development, without an increased consumptive demand on water (Maleri et al. 2008).

There was a need to conduct a study to develop a sustainable integrated fish–crop production system to address rural poverty and unemployment in Limpopo province. The selection of appropriate methods for any particular water body depends on local, social, and economic conditions and priorities (FAO 2008).

Aquaculture and fisheries opportunities in Limpopo Province could be further developed through aquaculture innovation, including some minor repairs and rehabilitation of the deserted dams, which were lying fallow. These freshwater reservoirs could be developed for aquaculture to improve rural livelihoods through integrated agriculture–aquaculture production systems. This kind of improved infrastructure can support both agriculture and aquaculture.

Study Objectives

The objective of the study was to develop a sustainable integrated fish-crop production system for Limpopo Province that would contribute to

- reducing poverty,
- creating jobs,
- generating income, and
- reducing food insecurity.

Study Method

The total area of 6,000 m^2 surrounding the dam was surveyed and prepared for the rehabilitation of the dam for the integrated aquaculture production system. The dam area was prepared by excavating with earthmoving machines to construct four earthen fish ponds of different sizes. The aquaculture production system was designed and developed to allow each of the four fish production ponds to be independent, such that each pond had its own inlet and outlet to regulate water levels. A 250-mm unplasticized polyvinylchloride pipe was used as an inlet channel to convey water from the canal to the ponds gravitationally. The inlet pipe was placed 2 m under the ground inside the pond wall with a slope of 1:1,000. The tee pipes were connected onto the main pipe into each pond to guide the inlet pipes. Each inlet was fitted with a valve and a 150-mm rising spindle to control water levels. This was done in a way to reduce costs and regular maintenance of the pipes. The soil on the embankments and floor of the ponds was compacted with the application of Bentonite to stabilize the soil to prevent any seepage that may occur.

A pump house was built near the outlet structure of one pond, and an electric pump was installed inside to pump water to the crop fields for irrigation. The intention was to minimize fertilizer inputs to crop fields by using water for fish farming and later directing the nutrient-enriched water from ponds to crop fields. The Department of Agriculture provided support to farmers through government support programs to rehabilitate the dam and cover the first production costs.

The minimum capacity of the completed pond production system was 55,000 kg for Mozambique Tilapia *Oreochromis mossambicus* (also known as *Tilapia mossambica*), Common Carp *Cyprinus carpio*, and Sharptooth Catfish *Clarias gariepinus* at a stocking density of 15 fish/m^2 under limited breeding space. Under normal circumstances, fish reared in fertilized ponds are harvested two times per annum. This will double the stocking capacity, as well as increase gross income. The estimated gross income is about $2,198.12 per harvest; thus, having two harvests per year doubles the total annual income to an amount of $4,396.24.

Table 1 below indicates different dimensions and expected income of the developed fish production system.

Upon completion, the fish ponds were covered with bird netting to protect fish from predatory birds such as cormorants, kingfishers, herons, hammerhead storks, and others that can cause huge damage to fish stocks. A 5-m^2 grid of plain wire provided proper support to the bird net.

Pond preparations

All four ponds were fertilized with agricultural lime and fresh chicken manure on the dry bottom to assist the growth of zooplankton as natural food for the juvenile fish before the ponds were filled and the fish stocked. Ponds were filled with water up to the level of 30 cm and left for a period of 7 d to increase zooplankton abundance. After 7 d, ponds levels were topped up to 1.2 m and left for another 7 d before the fish were stocked. The presence of zooplankton was checked repeatedly and regularly using microscopes prior to the stocking of fish.

Fish stocking

Polyculture was used in all four ponds of the production system. African Catfish, Common Carp, and Mozambique Tilapia were stocked and mixed in all ponds at the average mass of 5 g. The Department of Agriculture supported farmers with the first batch of fingerlings from the government-owned hatchery. Fish were fed manually three times a day with commercial trout feed, which contained 38% protein for the period of 120 d after stocking. At the time of harvesting, after a period of 120 d, fish attained an average mass of 1,500 g for African Catfish, 1,200 g for Common Carp, and 500 g for Mozambique Tilapia.

Job Creation

During the rehabilitation of the dam for construction of aquaculture ponds, the contractor employed 30 people from the local village to assist on the project for a period of 8 months. The employees included a community local officer, a health safety officer, bricklayers for building a pump-house and monk pond outlets, welders, and other people with various skills, including pipe laying and soil leveling on the bottom of the ponds and embankments.

Since the facility started operating, 110 temporary employees were hired annually during intervals of 4 months to assist with fish harvesting. More than 48 permanent employees were appointed for fish-farming-related activities such as feeding, netting, and ponds maintenance.

Income Generation

Apart from earning money from crops, farmers increased their income by selling fish to the retailers and local markets. Farmers earned an annual estimated combined income of up to $4,396.24 from fish sales. This income was

Table 1.—Expected income per harvest from fish production system.

Pond no.	Pond size (m^2)	Fish	Stocking density	Estimated income (US$)
1	920	13,790	15 fish/m^2	551.60
2	830	12,453	15 fish/m^2	498.12
3	950	14,276	15 fish/m^2	571.04
4	960	14,432	15 fish/m^2	577.36
Totals	3,660	54,951		2,198.12

used to pay salaries and for maintenance of the facility. Forty-eight farmers were involved in the day-to-day running of the project.

Results

A freshwater storage or balancing dam was rehabilitated for aquaculture production, which diversified water use for fish and agricultural production. Fish of various marketable sizes were obtained and sold to the market to generate income for the farmers. The research yielded positive results of up to 55 metric tons of fish to the value of $4,395.14. The mean increase in income of the farmers for the first period of three consecutive production cycles was $131.00, $197.00, and $255.00, respectively.

More than 140 temporary and 48 permanent jobs were created for local people who benefitted directly and indirectly from this aquaculture production.

On the side of agriculture, farmers benefited from the nutrient-rich water coming from the fish ponds. Farmers harvested 20 metric tons of maize with a value of $10,000.00 and 30 metric tons wheat worth $10,500.00, as compared to the low harvest of 15 metric tons of maize worth $7,500.00 and 25 metric tons wheat worth $8,750.00 harvested prior to the use of fish pond water. Farmers saved some money as profit and purchased fewer fertilizers for the crops.

Discussion

The communities surrounding the ponds benefitted from the project as they secured permanent and temporary jobs to sustain their livelihoods. Previously, the local community members were not able to receive any remuneration. During the establishment of the ponds, however, their lives were improved because they were able to secure food and income to afford household needs. Local people`s situation has improved in terms of food security by having fish as part of their everyday diet. In terms of health, fish is a highly nutritious food with high protein content, which is important for combatting malnutrition.

Challenges

The Limpopo Department of Agriculture had to mobilize funding to rehabilitate the deserted dam on behalf of the farmers as part of a poverty alleviation program. Farmers had to obtain water rights from the Department of Water Affairs and obtain Environmental Impact Assessment authorization from the Department of Economic Development, Environment and Tourism to utilize water and rehabilitate the dam for fish farming.

Farmers had to incur costs to purchase commercial fish feed to speed up production within the relatively short production period. Farmers also experienced challenges with obligatory costs of pumping water from the fish ponds to irrigate the fields. All the costs incurred were covered by fish and crop sales.

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Capture Fishery in Relation to Nile Tilapia Management in the Mountainous Lakes of Pokhara Valley, Nepal

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Abstract.—Nepal is rich in water resources and fishing is a longstanding tradition. Capture fisheries are an important sector in Nepal and contribute approximately 0.5% to the national gross domestic product. The fish catch data of the Phewa, Begnas, and Rupa lakes of the Pokhara Valley from 2006 and 2011 were analyzed to determine the harvest trends of the exotic Nile Tilapia *Oreochromis niloticus* and native fish. The harvest of Nile Tilapia increased and the harvest of native fish species decreased in the lakes of Pokhara Valley. Harvest from the capture fisheries has increased in these lakes since Nile Tilapia became established. The introduction of Nile Tilapia in these lakes was accidental. Due to an increase in Nile Tilapia catches, the income of the Jalari community has increased, enhancing its livelihood. The native fishes of the Pokhara Valley lakes, however, are highly valued and provide a direct livelihood for the Jalari community living around the lakes. Population growth, urbanization, tourism, agricultural intensification, illegal fishing, and the introduction of exotic fish species are the drivers that affect the capture fisheries in Phewa, Begnas, and Rupa lakes. Regular monitoring and stock enhancement programs for native fish species and selective harvesting of Nile Tilapia will mitigate the problem of overpopulation of Nile Tilapia. To control further expansion of Nile Tilapia into other natural lakes, reservoirs, and rivers of Nepal, native fish conservation policy, laws, and protocols should be rigorously enforced. This paper discusses the drivers of fisheries, the increasing trend of Nile Tilapia in total fish catch, and its possible effect on native fish species and the livelihood of dependent communities of the lakes of the Pokhara Valley.

Introduction

Inland fisheries contribute about 10–12% to annual global fisheries production (FAO 2012) and are an important source of income and livelihood (Welcomme et al. 2010; Suuronen and Bartley 2014). Supply of fish from inland waters is critically important for human nutrition (UNEP 2010). Fish populations in Asia are heavily exploited (Welcomme et al. 2010). Inland fisheries harvest could be increased by fishery enhancement practices (Welcomme et al. 2010; Suuronen and Bartley 2014).

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Nepal is rich in water resources and fishing is a longstanding tradition (Gurung et al. 2005). Rivers (395,000 ha), lakes (5,000 ha), reservoirs (1,500 ha), marginal swamps and wetlands (1,100 ha), and irrigated rice fields (398,000 ha) are the main sources of the capture fisheries in Nepal. Capture fisheries are an important sector of fisheries in Nepal and contribute approximately 38% of the total fish production (49,730 metric tons) in the country (DOFD 2011–2012). The capture fisheries contribute 0.5% to the national gross domestic product (Gurung 2012). The Directorate of Fisheries Development (DOFD 2007–2008) estimated that a total of about 107,000 families are involved in capture fisheries in natural waters in Nepal. The capture fisheries involve about 427,000 active members and approximately 580,000 direct beneficiaries. About 6.6% of the economically active population in the agriculture sector is engaged in the capture fisheries (Wagle and Gurung 2011). There are 24 ethnic communities whose livelihoods are dependent on fisheries in Nepal (Mishra and Upadhya 2011). The communities involved in fishing activities are mostly the Tharu, Majhi, Malaha, Danuwar, Kewat, Bote, Mushar, Mukhiya, Darai, Kumal, Dangar, Jalari, Bantar, and Rai (Gurung et al. 2005).

In the Pokhara Valley, Phewa Lake is largest (443 ha), followed by Begnas Lake (328 ha) and Rupa Lake (135 ha). The capture fisheries in these lakes are traditional. Jalari, a deprived ethnic minority fishing community, has a history of nomadic life, and approximately 300 families are spread throughout the Pokhara Valley lakes (Gurung and Bista 2003). Fishing is the main occupation of the Jalari community around these lakes (Wagle et al. 2007). Gill nets were introduced in the Pokhara Valley in the 1960s to increase the daily catch for the Jalari's livelihood (Rajbanshi et al. 1984). The capture fisheries of these lakes comprised both native and exotic fish species (Gurung 2003). Nineteen, seventeen, and sixteen native fish species, as well as four exotic fish species, have been recorded from the Phewa, Begnas, and Rupa lakes, respectively (Pokharel 2000). Nile Tilapia *Oreochromis niloticus* were introduced into Nepal from Thailand in 1985 for aquaculture (Shrestha 1994). Nile Tilapia were introduced accidently in the lakes of the Pokhara Valley and first appeared in catches there during 2003 (Nepal 2008). The main goals of fisheries management in the Phewa, Begnas, and Rupa lakes are to conserve the native fish species and improve the livelihood of the Jalari fisher community.

Native fish diversity in Nepal includes 228 fish species (Shrestha 2012). Native fishes are important for the livelihood, nutrition, and welfare of the rural people. Their livelihood may be affected by a decline in native fish catch. To achieve sustainable use, appropriate planning for conservation and development of management strategies is of the utmost importance. This paper discusses the drivers affecting capture fishery and the increasing trend of Nile Tilapia in total fish harvest, their possible effect on native fish species, mitigation practices, and the effect on the livelihood of the dependent communities of lakes Phewa, Begnas, and Rupa in the Pokhara Valley.

Methods

Study sites

Phewa Lake is situated in the southwestern part of the Kaski district at 28.1°N and 82.5°E, 742 m above mean sea level (Figure 1). The watershed area of this lake is 110 km^2 (Ferro and Swar 1978). Lamichhane (2000) estimated the water surface area of this lake to be 443 ha with a maximum depth of 23 m. Phewa Lake is fed by two perennial streams. This lake fluctuates between mesotrophic and eutrophic in different seasons (Husen et al. 2009a, 2011).

Begnas Lake is the second biggest lake (328 ha) at 28°10'26.2″N and 84°05'50.4″E, 650 m above mean sea level (Figure 1). It is fed by a perennial stream with a catchment area of 19 km^2 and an average depth of 6.6 m (Rai et al. 1995). This lake fluctuates between oligotrophic and mesotrophic in different seasons (Husen et al. 2009b, 2011, 2012).

Lake Rupa (135 ha) is the third biggest lake and its watershed is located between 28°08'N to 28°10'N and 84°06'E to 84°07'E, at 600 m

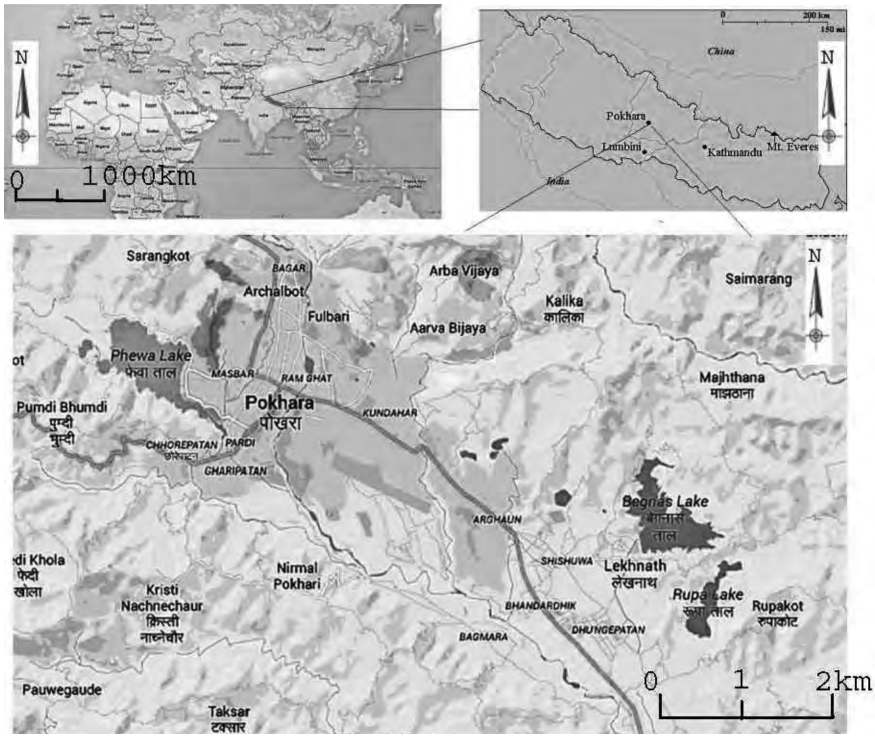


Figure 1.—Map showing the location of Nepal in Asia, the location of the Pokhara Valley in Nepal, and the Pokhara Valley lakes.

above mean sea level (Figure 1). The lake's total catchment area is 30 km^2. The surface area, maximum depth, and average depth of the lake are 1.35 km^2, 6 m, and 3 m, respectively. This lake is eutrohic (Husen et al. 2011, 2013).

Data collection and statistical analysis

The daily catches (kg) of fish species were recorded from the landing sites of the Phewa, Begnas, and Rupa lakes of the Pokhara Valley. The fish catch data for the years 2006 and 2011 were analyzed to determine the percent contribution of Nile Tilapia and native species in the capture fishery from these lakes. Information about the types of gears, fish species, and drivers of fisheries (environmental, political, social, economic, and human induced) were gathered from Jalari fishers through interviews with semi-structured questionnaires. The percent composition of the catches in the year 2006 was compared to the year 2011 to determine changes in fish catches in these lakes.

Results

Fishing gear and fish species

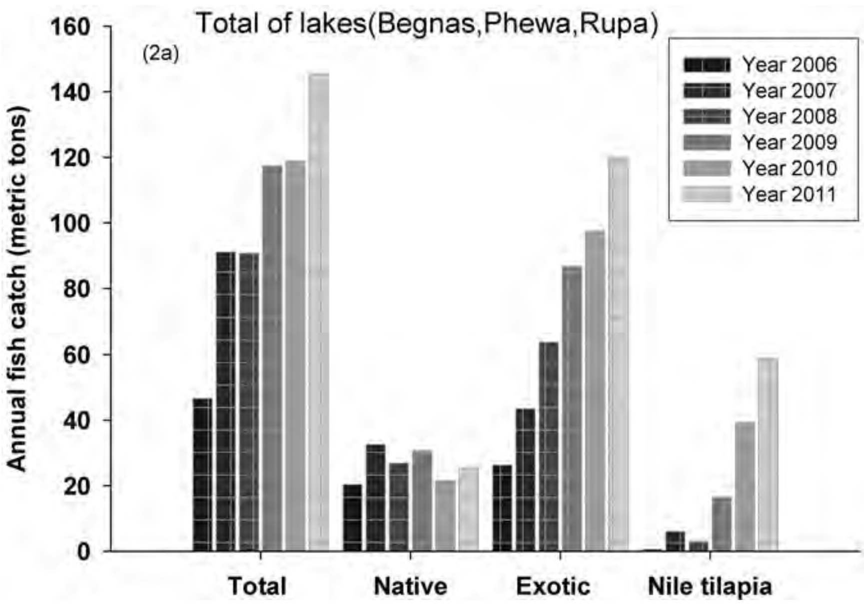
The major types of fishing gears used by Jalari fishers in the lakes of Pokhara Valley during 2006 and 2011 were gill nets, cast nets, and fish hooks. Gill nets 350–450 m^2 were the most common fishing gear, with different mesh sizes to capture small to large fish. The fish species in the catch of Pokhara Valley Lakes Phewa, Begnas, and Rupa in 2006 and 2011 are presented in Table 1. In 2011, 24 fish species were captured; 18 were native fish and 6 were exotic (Table 1).

Capture fishery and catch trends

Total annual fish harvest from Lakes Phewa, Begnas, and Rupa increased from 46.7 metric tons in 2006 to 145.6 metric tons in 2011. During this time, Nile Tilapia catch from these lakes increased from 0.6 metric tons in 2006 to 58.1 metric tons in 2011 (Figure 2a). Contri-

Table 1.—The contribution (%) of fish species to total annual harvest (metric tons) from the Phewa, Begnas, and Rupa lakes during 2006 and 2011. Percent contribution to total catch (–) = did not appear in catches.

			Contribution (%) to total annual harvest					
			Phewa Lake		Begnas Lake		Rupa Lake	
Scientific name	English name	Local name	2006	2011	2006	2011	2006	2011
Native fish species								
Tor putitora (Hamilton)	Putitor Mahseer	Sahar	1.7	1.52	1.6	0.66	0.12	0.06
Neolissochilus hexagonolepis (McClelland)	Copper Mahseer	Katle	1.02	0.72	–	–	0.11	–
Cirrhinus reba (Hamilton)	Reba	Rewa	2.5	0.52	–	0.15	–	–
Barilius barna (Hamilton)		Lam Fageta	0.34	0.39	–	0.85	–	
Barilius bola (Hamilton)	Trout Barb	Fageta						
Barilius vagra (Hamilton)		Fageta						
Barilius bendelisis (Hamilton)		Fageta						
Puntius sarana (Hamilton)	Olive Barb	Kande	0.25	0.31	–	–	–	–
Puntius sophore (Hamilton)	Pool Barb	Bhitte/Bhitta	34.91	6.77	10.6	7.9	7.69	0.01
Puntius titius (Hamilton)		Bhitte/Bhitta						
Puntius ticto (Hamilton)	Ticto Barb	Bhitte/Bhitta						
Cirrhinus mrigala (Hamilton)	Mrigal	Naini	0.51	0.55	1.5	7.71	6.92	2.27
Catla catla (Hamilton; also *Gibelion catla*)	Catla	Bhakur	0.67	1.11	9.2	3.23	9.5	2.29
Labeo rohita (Hamilton)	Rohu	Rohu	1.63	0.26	1.7	0.95	24.81	11.89
Mastacembelus armatus (Lacepede)	Tiretrack Eel	Chuche Bam	3.91	2.16	0.7	2.06	0.34	–
Xenentodon cancila (Hamilton)	Freshwater Garfish	Dhunge Bam						
Clarias batrachus (L.)	Walking Catfish	Magur	5.88	–	0.2	0.03	0.15	0.05
Mystus bleekeri (Day)	Day's Mystus	Junge	–	–	0.01	0.02	0.01	0.01
Exotic fish species								
Hypophthalmichthys nobilis (Richardson)	Bighead Carp		13.2	23.54	13.7	4.76	6.13	34.78
Hypophthalmichthys molitrix (Valenciennes)	Silver Carp		15.39	17.83	52.2	4.84	14.71	27.09
Ctenopharyngodon idella (Valenciennes)	Grass Carp		4.34	1.79	6.5	0.26	14.89	2.78
Cyprinus carpio (L.)	Common Carp		1.54	0.23	0.6	0.37	14.33	6.6
Clarias gariepinus (Burchell)	Sharptooth Catfish (also known as African Magur)		10	–	0.3	0.03	0.25	0.1
Oreochromis niloticus (Linnaeus)	Nile Tilapia		2.22	42.3	1.2	66.19	0.08	12.1



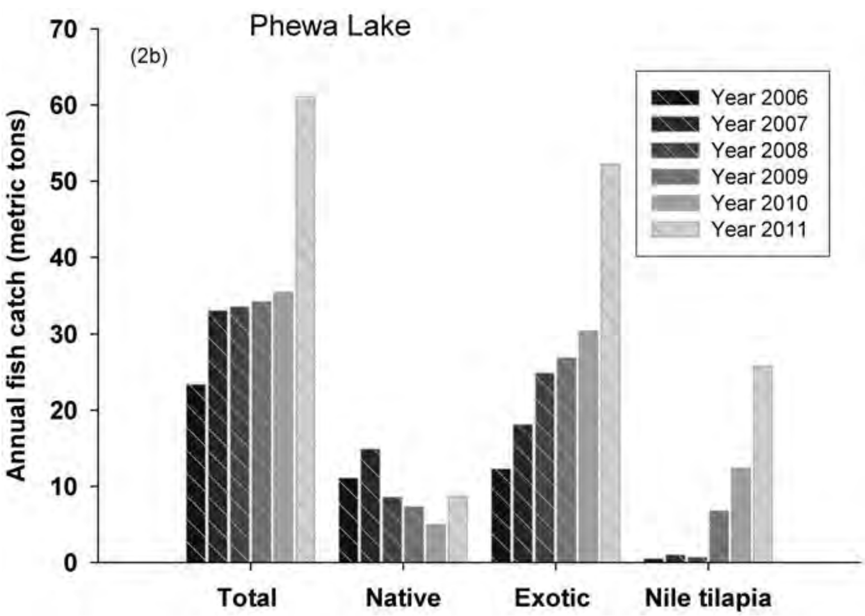


Figure 2.—Catch (metric tons) trends of native fish, exotic fish, and Nile Tilapia in the lakes of the Pokhara Valley. Total catch of **(a)** all lakes, **(b)** Phewa Lake, **(c)** Begnas Lake, and **(d)** Rupa Lake.

butions of exotic fish species were 86.3, 76.5, and 83.5% of the total fish catch of the Phewa, Begnas, and Rupa lakes, respectively, in 2011.

Phewa Lake

Annual total fish harvest increased in Phewa Lake (Figure 2b) and native fish catch decreased through time. The contribution of native fish to total annual fish harvest declined by 32.8% while that of Nile Tilapia increased by 40.1% in 2011, as compared to 2006 (Figure 3a, 3b). Annual fish yield was 52.8 kg/ha in 2006 and increased to 137.9 kg/ha in 2011. Likewise, Nile Tilapia contributed 1.13 kg/ha

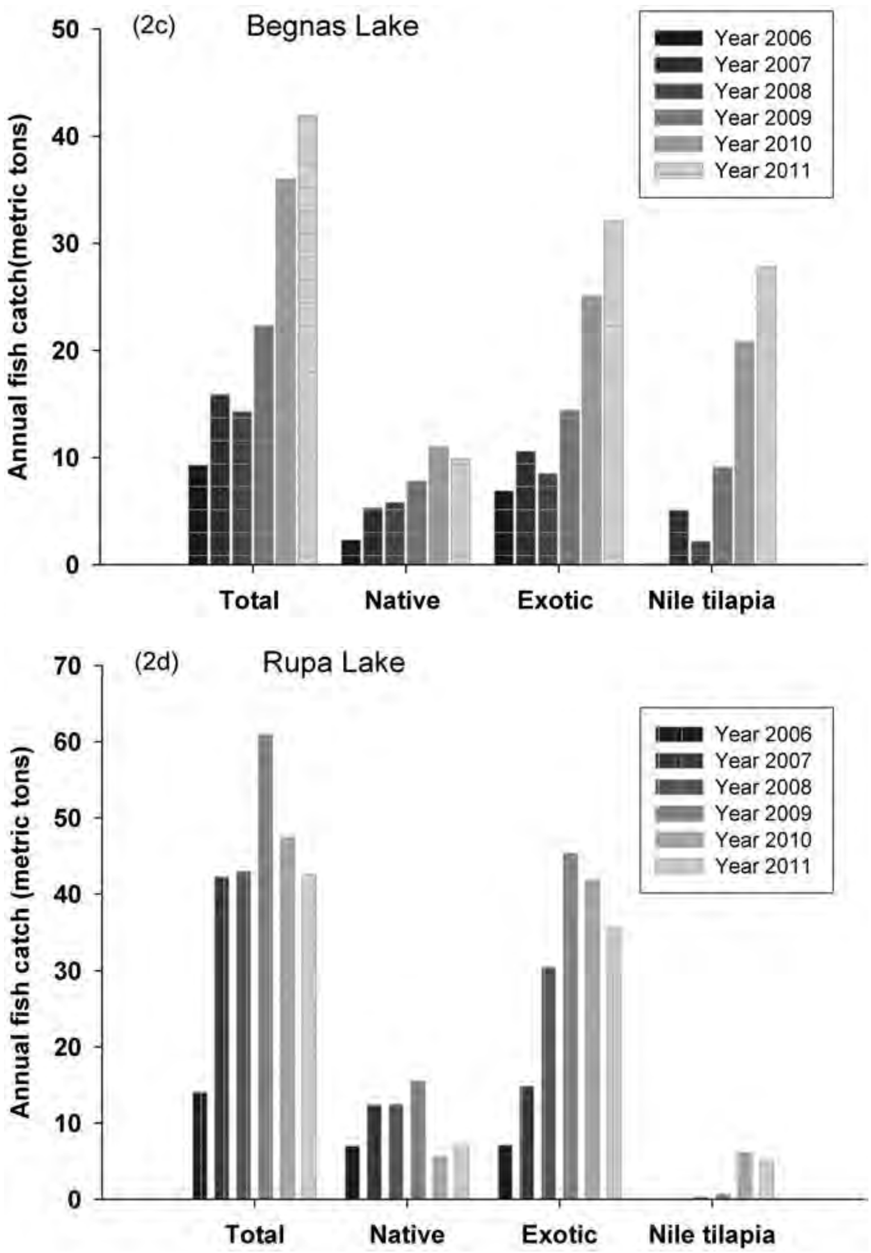


Figure 2.—Continued.

to the annual fish yield of Phewa Lake in 2006 and increased to 58.2 kg/ha in 2011. There were shifts in contribution (%) of fish species to annual catches during the study period in Phewa Lake. *Puntius* spp. contributed the highest amount (34.9%) to the total harvest of Phewa Lake in 2006 while Nile Tilapia (42.3%) contributed the highest in 2011.

Begnas Lake

Annual total fish harvest from capture fishery increased in Begnas Lake (Figure 2c). Native fish catches decreased in 2011. Nile Tilapia percent contributions to the total annual fish catch were 65% in 2011, as compared to 2006 (Figure 3a). Annual fish yield was 28.3 kg/ha in 2006

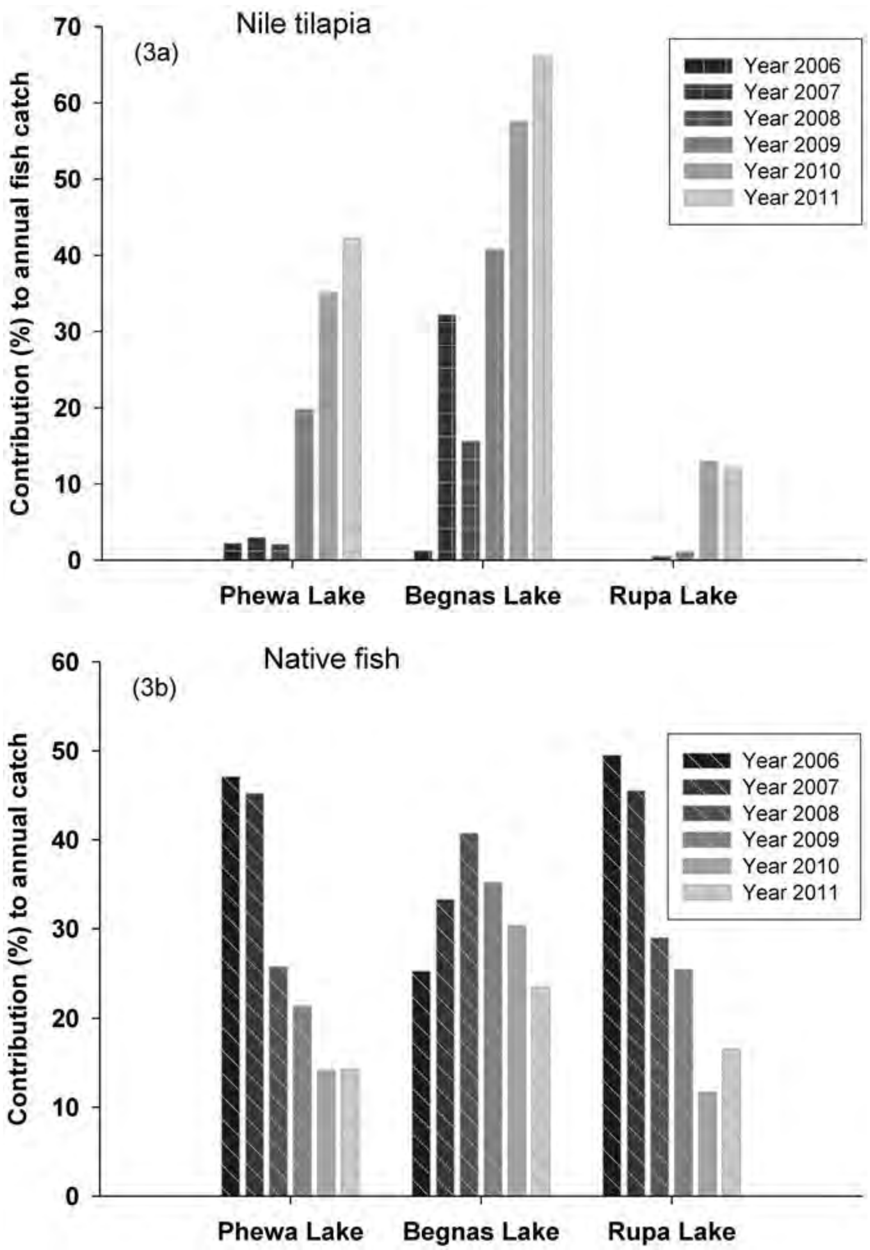


Figure 3.—The trend of contribution (%) to the total annual catch (metric tons) of **(a)** Nile Tilapia and **(b)** native fish in the lakes of the Pokhara Valley.

and increased to 127.8 kg/ha in 2011. Similarly, Nile Tilapia contribution to the annual fish yield was 0.34 kg/ha in 2006 and increased to 84.7 kg/ha in 2011. There were shifts in contribution (%) of fish species to annual catches in Begnas Lake during the study period. Silver Carp contributed the most (52.2%) to the total annual harvest from Begnas Lake in 2006 while Nile Tilapia contributed the most (66.2%) in 2011 (Table 1).

Rupa Lake

Contributions of exotic fish species in the total annual fish catch increased by 33% in recent years, with Nile Tilapia increasing by 12.02% in the year 2011 as compared to the year 2006 (Figure 3a). There were decreasing trends of native fish species catches in Rupa Lake (Figure 3b). The annual fish yield of Rupa Lake was 109.8 kg/ha in 2006 and increased to 332 kg/ha in 2011. Similarly, Nile Tilapia contribution to annual fish yield was 0.08 kg/ha in 2006 and increased to 40.23 kg/ha in 2011. There were shifts in contribution (%) of fish species to annual catches in Rupa Lake in the year 2011 as compared to the year 2006. Rohu contributed most (24.81%) to total harvest from Rupa Lake in 2006 while Bighead Carp contributed most (34.8%) in 2011.

Stock Enhancement

Stock enhancement was carried out in the lakes of Pokhara Valley during 2006–2011 to increase fish production. Eighty-five to ninety percent of stocked fingerlings in these lakes were native fish species. The native fish species stocked were Putitor Mahseer, Rohu, Catla, and Mrigal, and exotic fish were Silver Carp, Bighead Carp, and Common Carp.

Fish sales and fisher income

The marketing of harvested fish from the lakes is managed by a fish entrepreneurs committee or cooperative of respective lakes. The total estimated revenue from the sale of fish from the capture fisheries increased from 10.45 Nepalese rupees (NR) in 2006 to NR38.97 million. Nile Tilapia sales increased from NR0.08 million in 2006 to NR13.51 million in 2011. However, native fish of the Pokhara Valley lakes have their own importance. The native fish of the Pokhara Valley lakes are highly valued, fetching a high price in the market due to their taste and consumer priority in comparison to exotic fish (Figure 4). Despite reduced harvest, native fish provide high income, which directly supports the livelihoods of the Jalari fishers in the communities around the lakes. Small native fish species such as *Puntius* sp. and *Barilius* sp. are nutrient-rich fish, which could help

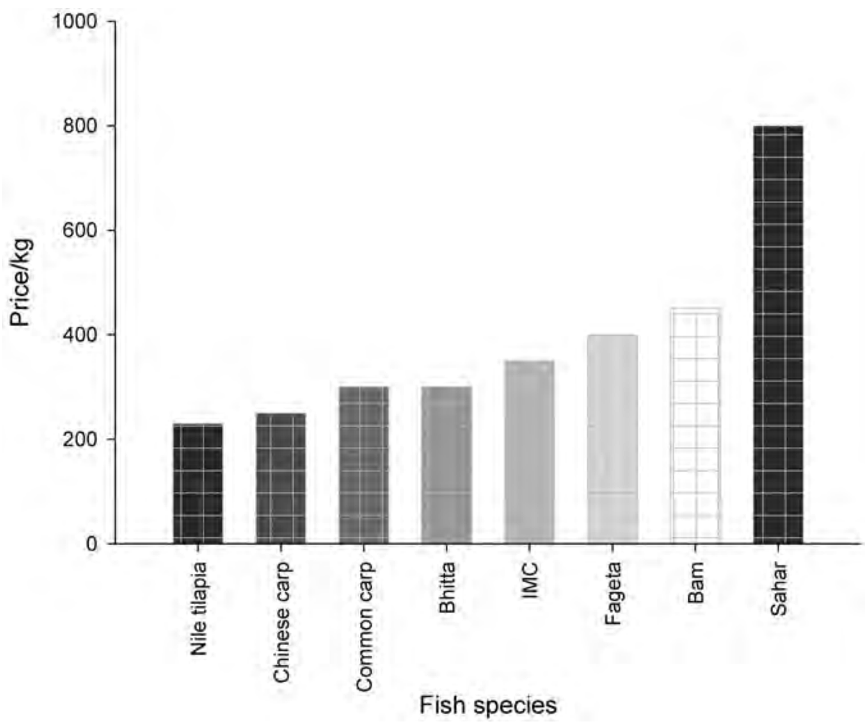


Figure 4.—Sales of fish (price given is in Nepalese rupees per kilogram) at the landing sites of the Phewa, Begnas, and Rupa lakes of Pokhara Valley.

reduce malnutrition in women and children of the Pokhara Valley. Tiretrack Eel has also been used for medicinal purposes by peoples of the Pokhara Valley.

Drivers of Fisheries

The main drivers affecting the capture fisheries in lakes Phewa, Begnas, and Rupa are population growth, urbanization, tourism, agricultural intensification, illegal fishing, and the introduction of exotic fish species. Due to the intensification of agriculture, tourism, and urbanization in the catchment area, pollution and eutrophication increased in these lakes. These lakes are also facing the problems of siltation and encroachment of lake shoreline by local people to make agricultural land. The water quality of the lakes has changed due to anthropogenic activity in the catchments area of these lakes. There is also conflict of ownership among stakeholders of the Pokhara Valley lakes.

Discussion

Shifts in species composition

We found that there were shifts in composition and contributions of fish species in the Phewa, Begnas, and Rupa lakes. In comparison to Pokharel (2000), two new exotic fish (Nile Tilapia and Sharptooth Catfish *Clarias gariepinus*) were recorded from the Pokhara Valley lakes. In addition, we found fish species from each lake that were collected early in the study that were not collected in 2011. According to Jalari fishers, the presence of Faketa, Chuche, and Dunge Bam, Junge, and Rewa are still in the Pokhara Valley lakes, but Katle and Kande are now totally absent in the Begnas and Rupa lakes. The present findings revealed that the native fish contribution declined and Nile Tilapia increased in the catches from these lakes. Such changes may be due to the following drivers: population growth, urbanization, tourism, agricultural intensification, illegal fishing, and the introduction of exotic fish species in lakes Phewa, Begnas, and Rupa. The present findings indicate that the status of these native and exotic species should be monitored intensively. The findings from catch data analyses in these lakes are alarming and stress the need for the conservation of native fish species.

Nile Tilapia and possible impacts

Nile Tilapia were introduced accidently in the lakes of the Pokhara Valley and first appeared in catches during 2003 (Nepal 2008). We found that there were noticeable increasing harvests of Nile Tilapia. The probable reasons for the successes of the Nile Tilapia are due to its wide degree of environmental tolerance, diverse diet, long life span, high variability in life history traits in response to environmental conditions, flexibility, peculiar reproductive characteristics, and aggressive behavior towards other fish (Njiru et al. 2004, 2008; Peterson et al. 2004; Grammer et al. 2012; Ishikawa et al. 2013). Nile Tilapia has caused a change in the dynamics of the fisheries of the Ganga River (Singh et al. 2014). Therefore, the effects of Nile Tilapia and other exotic species on native fish species should be monitored regularly and managed properly in the lakes of the Pokhara Valley.

Livelihood and Nile Tilapia management

Nile Tilapia increased the income of the Jalari fishers in the Pokhara Valley in recent years. It is due to an increase in total fish harvest from these lakes, with major contributions by Nile Tilapia. This study showed that Nile Tilapia alone provided revenue of NR13.51million in the year 2011 to the Jalari communities. The livelihood of the Jalari fishers in the Pokhara Valley was enhanced by the capture fisheries with a rise in income and other indicators of well-being (Wagle et al. 2012).

The populations of Nile Tilapia must be balanced in these lakes for a sustainable yield and to decrease negative impacts on native fish species. To mitigate the increasing trends of Nile Tilapia, a stock enhancement program of native fish species and targeted fishing of Nile Tilapia should be carried out on regular basis in the lakes of Pokhara Valley. Putitor Mahseer is a natural control for overrecruitment of tilapia (Shrestha et al. 2011). One way to mitigate the impact of Nile Tilapia is to increase the population of Sahar by stock enhancement in the lakes of the Pokhara Valley. Well-planned and carefully considered stocking programs can enhance the productivity of waters, as well as improve the quality and profitability of fishing (Suuronen and Bartley 2014).

Future strategy for Nile Tilapia managements

There are no known methods to completely eradicate Nile Tilapia from natural water once introduced (Stauffer et al. 1988; McCrary et al. 2007). Invasions of Nile Tilapia in lakes, rivers, floodplains, and wetlands are especially problematic because they are difficult to manage. The recommendation to use totally closed aquaculture systems and a strict ban on tilapia cultivation and transportation in natural watersheds by McCrary et al. (2007) is very practical and would be applicable to Nepal. To avoid further spread of tilapia, it is necessary to regulate aquaculture activities and fisheries management and to develop policies to screen invasive species before introduction into new areas (Esselman et al. 2013). The best form of management for Nile Tilapia in Nepal will be prevention from introduction to new natural resources such as lakes, reservoirs, and rivers. Fish diversity and conservation is one of the neglected areas of research and development in the fisheries sector in Nepal. For conservation of the aquatic life, the Aquatic Life Conservation Act of 1961 was promulgated. However, due to insufficient enforcement, the rules and regulations set out in this act are hardly followed (Gurung 2003). It is difficult to manage the aquatic resources in developing countries due to lack of baseline data and limited investment in research and monitoring (Pringle et al. 2000). To ensure native fish conservation, significant improvement in law enforcement with a high level of understanding is essential (Gurung 2012).

Conclusions

Continuous and regular monitoring of the biological and population parameters of fish in the lakes of the Pokhara Valley is essential to provide accurate, updated information relevant to fisheries management. Regular monitoring of water quality and fish catches data should be continued. The population of Nile Tilapia should be regulated by stock enhancement programs for native fish species and using selective gear for tilapia population control in the Phewa, Begnas, and Rupa lakes. Biosecurity could be one of the strategies for controlling invasive species spread into other natural lakes, reservoirs, and rivers, in order to protect the native fish species in Nepal. Public awareness is also needed to reduce further expansion of Nile Tilapia and other exotic fish in natural waters. The impact of Nile Tilapia on native fish could not be verified by the catch landing data only. Further scientific study is needed to verify the impact of Nile Tilapia in the lakes of the Pokhara Valley.

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Moving towards Effective Governance of Fisheries and Freshwater Resources

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Abstract.—Governance of fish, fisheries, and freshwater resources encompasses both ecological and human well-being. Nevertheless, achieving both is challenging because of the diverse sectors competing for finite resources. This challenge is not related to a lack of understanding of what contributes to effective governance, but rather is due to the tendency to divide freshwater resource users into sectors that do not coordinate their use of freshwater. A panel of experts identified six issues and recommendations for improving governance of inland fisheries. These issues are (1) the lack of cross-sectoral integration in the development and management agendas for freshwater ecosystems, (2) the need for governance mechanisms on shared water bodies, (3) the recognition of the rights and wishes of indigenous people and other stakeholders dependent on inland fisheries, (4) recognizing the important role of aquaculture and how to incorporate aquaculture into governance mechanisms, (5) how to improve fishery management, and (6) how to improve communication among institutions and stakeholders.

To facilitate addressing these six issues, this paper systematically explores how governance of inland freshwater resources, and specifically freshwater fisheries, can be made more effective by focusing on the following:

1. Guiding principles of governance—the values and ideals that guide the process of governing;
2. Governing institutions—those that are charged with overseeing and controlling

the governance processes by which problems are solved and opportunities created; and

3. Opportunities and solutions—the manner, method, and system by which the fishery sector is governed, including the policies and management actions that are the tasks of fishery managers and policymakers for the fishery sector, and the need for more integration between all sectors using freshwater.

Introduction

It is becoming critical that a more effective approach for governing freshwater is implemented that comprehensively addresses competing demands from different sectors using freshwater. Currently, about 9% of the globally accessible freshwater is withdrawn annually for human uses (Comprehensive Assessment of Water Management in Agriculture 2007). A large quantity (70%) of this water is diverted for agricultural use, with industrial (20%) and domestic uses (10%) being the next two largest consumers (Comprehensive Assessment of Water Management in Agriculture 2007). The freshwater used by these nonfisheries sectors ultimately reduces the quantity and quality of freshwater available for inland fish production, including both aquaculture and capture fisheries. The demand for freshwater will continue to rise with growing human population, further increasing conflict related to the use of freshwater. J. Bruinsma (paper presented at the FAO Expert Meeting on How to Feed the World in 2050, 2009, cited in FAO 2014a) estimated that water withdrawals will double by 2050, mainly to satisfy the increase in demand for agricultural food production.

Effective governance of freshwater is an important component of achieving efficacy of policies, and management activities. It is important to recognize the external influences acting on the freshwater ecosystem and fish. Fishery governance can no longer operate in isolation from other sectors using freshwater. Policymakers, fishery managers, and fishers need to increase their understanding of and engagement with other sectors that can impact freshwater ecosystems and, thus, the livelihoods and well-being of those in the fishery sector.

A panel of experts who attended the global conference on inland fisheries identified six issues and recommendations for improving governance of inland fisheries. These issues are

1. The lack of cross-sectoral integration in the development and management agendas for freshwater ecosystems;
2. The need for governance mechanisms on shared water bodies;
3. The recognition of rights and wishes of indigenous people and other stakeholders dependent on inland fisheries;
4. Recognizing the important role of aquaculture and how to incorporate aquaculture into governance mechanisms;
5. How to improve fishery management; and
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- Opportunities and solutions—the manner, method, and system by which the fishery sector is governed, including the policy and management actions that are the tasks of policymakers and fishery managers.

What Is Governance?

Governance is a broad term used to describe the institutions and instruments that guide the decision-making processes used in policy and management (FAO 2014d). Governance occurs at the local, national, regional, and international levels. Various definitions of governance exist. For the purpose of this review, the following aspects, drawn from three accepted definitions, are used:

> Governance is the whole of public as well as private interactions that [can be] initiated to solve societal problems and to create social opportunities (Bavinck et al. 2005; Kooiman et al. 2005);
>
> It includes the formulation and application of principles guiding those interactions and care for institutions that enable them. (Kooiman et al. 2005);
>
> Governance [is] a systemic concept relating to the exercise of economic, political, and administrative authority. It encompasses: (i) the guiding principles and goals of the sector, both conceptual and operational; (ii) the ways and means of organisation and coordination of the action; (iii) the infrastructure of socio-political, economic, and legal instruments; (iv) the nature and modus operandi of the processes; and (v) the policies, plans, and measures (Garcia 2009).

Governance is usually considered the responsibility of governments. However, as indicated by the above definitions, civil society organizations (i.e., the organizations such as nongovernmental organizations that promote the principles of society) and private industry must also share the responsibility for governance. How this responsibility is shared can vary depending on the situation, with different levels of participation, accountability, and transparency (Béné and Neiland 2006) leading to differing outcomes for resource sustainability.

Effective Governance of Inland Freshwaters to Promote Human and Ecosystem Well-Being

The governance of freshwater resources is challenging because of various sectoral activities relying on freshwater (e.g., Palmer et al. 2012; FAO 2014b; Box 1). Moreover, governance in the developing world is further complicated due to the dispersed nature of the inland fisheries (e.g., lack of formal landing sites, numerous small-scale fishers, and seasonal fishing).

A coordinated approach among the many jurisdictions and sectoral interests that are involved in allocating freshwater resources is necessary (Table 1, Issue: Cross-sectoral integration is lacking in development agendas for freshwater ecosystems; Issue: Improved governance, especially for shared water bodies is needed). Unfortunately, there is a tendency for policymakers to divide water-resource users into sectors and segregate governance based on sector and stakeholder interests (Table 2; Committee on Fisheries 1999). The larger the freshwater resource, the more problematic is this segregation. There are efforts to coordinate the sectors, such as the Mekong River and Laurentian Great Lakes (Boxes 2 and 3).

However, the coordination has not always been successful. Governance processes for these large freshwater systems and their fisheries can be intensely influenced, not only by interests and demands from multiple stakeholders at different geographic scales, but also by environmental drivers and stressors that interact and influence fisheries abundances within the lakes and rivers. Numerous initiatives by international organizations have attempted to promote effective governance, but they have not had much success in fully integrating the links among water, land, agriculture, fisheries, and food security (FAO 2014c).

Governance processes intrinsically link ecosystem well-being and human well-being (MA 2005; Lynch et al. 2011). Many of the ecological services provided by freshwater ecosystems contribute to human well-being. Freshwater ecosystems include lakes, rivers, and wetlands, as well as groundwater flows and aquifers that affect the quantity and quality of surface waters (e.g., groundwater upwelling that keep streams cool for coldwater fish species). Freshwater resources provide the basis for commercial, recreational, and subsistence fisheries; agriculture, municipal, and industrial uses; transportation; electricity generation; recreational activities; and scenic values

Box 1. Governance Reform: The Formation of the Lake Victoria Fisheries Organization

PAUL ONYANGO

Governance of Lake Victoria aquatic resources required a collaborative lake-wide authority to regulate and collect scientifically reliable fisheries statistics that could be used in its sustainable resource management. Several attempts to establish such an authority were made, with organizations being established, failing, and being replaced by another organization, which failed. Some of the failures were likely due to inadequate funding and capacity, and the lack of stakeholder involvement in their design and implementation. An example of this was the development of the Lake Victoria Fisheries Services, which was implemented by colonial government officials who, without stakeholder involvement, made all resource management and allocation decisions. The need for regional collaboration, however, persisted among the three riparian countries that surrounded Lake Victoria. Thus, between 1980 and 1995, Kenya, Tanzania, and Uganda established a subcommittee that focused on Lake Victoria fisheries as part of the Food and Agriculture Organization of the United Nations' Committee on Inland Fisheries of Africa in order to provide a forum for the development and management of the Lake Victoria fish and its fisheries. The subcommittee eventually led to the signing of the 1994 Convention for the Establishment of the Lake Victoria Fisheries Organization (LFVO), which entered into force on May 24, 1996 (LFVO 2001a).

The LFVO aims to foster cooperation among the three nations that have governance rights to Lake Victoria to harmonize the national measures of each for the sustainable development of the lake through the joint development and adoption of sustainable fisheries conservation and management measures (LVFO 1999; see Box Figure 1.1 below). For this governance system to work effectively, all those who had a stake (influence) in the fisheries were brought into the new governance arrangement, as mangers realized that Lake Victoria's fisheries could not be managed exclusively by the riparian governments and in isolation from other activities that would affect the ecology of the lake and its fisheries, such as agriculture and mining. Additionally, the LVFO has a clear communication system and transparent decision-making process that takes a multidisciplinary and cross-sectoral approach to the management of the fishery (LVFO 2001b). It has not been easy to build such a governance structure, but the riparian countries have been driven by the fact that the lake and its resources are important economic factors that can accelerate growth in this region and, if not taken care of properly, could destroy their economic base and societal well-being.

Box continues

(Aylward et al. 2005). Inland waters and their fisheries are increasingly being recognized for their role in ensuring food security, supporting livelihoods, and enhancing well-being of local and regional human communities (Berkes et al. 2001; FAO 2005). When freshwater ecosystems deteriorate, the fish and the human populations that rely on them for food and livelihoods also suffer (Committee on Fisheries 1999; Dobiez and Hecky 2011).

Holistic governance approaches that include all freshwater users would aid in identifying potential synergistic, neutral, or conflicting interactions (FAO 2010a). Syner-

Box 1. Continued

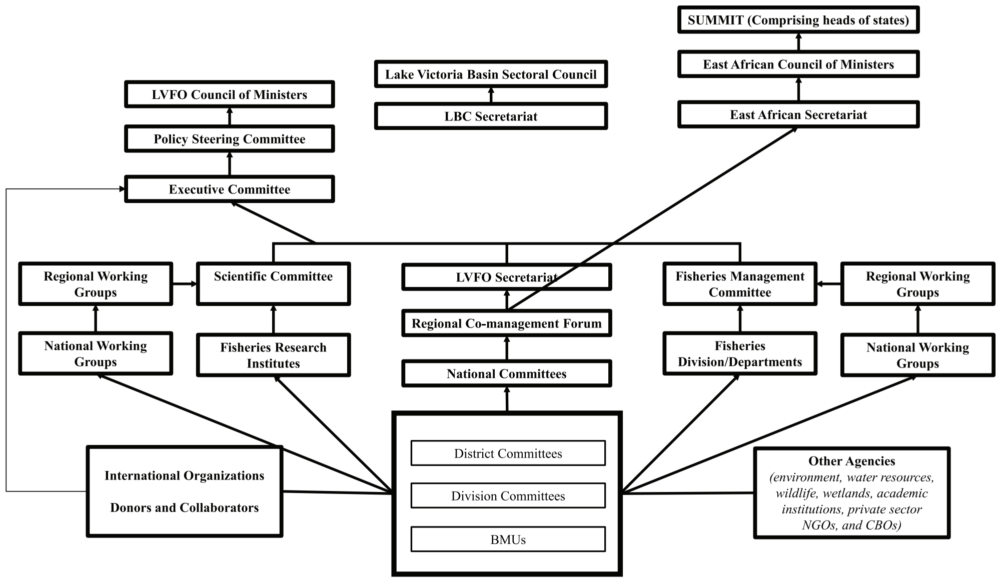

Figure Box 1.1.—Organizational structure in Lake Victoria.

gistic interactions can encourage cooperation among stakeholders, as all parties can benefit from collaboration and coordination, resulting in more sustainable freshwater resources. Addressing conflicting interactions and the impacts of one sector's actions on others are the most challenging issues for achieving coordination and collaboration. Nevertheless, the consideration of these challenges in the governance process and informed trade-offs (i.e. opportunities for intelligent compromise) may avert unintentional creation of additional social, economic, and ecological problems. The need for holistic governance approaches is also being voiced by other natural resources sectors including agriculture (Charlotte et al. 2014) and land tenure (FAO 2012a; Box 4). Recommendations about how to improve interactions among freshwater users include cross-sectoral integration, recognition of sectoral allies such as aquaculture, and improved communications among stakeholders (Table 1).

Governing Institutions

Endeavors to manage natural freshwater resources have taken many approaches and have developed governance institutions focused at different scales from the local to the international. These institutions are often focused on specific sectors and rarely address cross-sectoral issues or evaluate the total impact of all resource use. In some countries, this situation is exacerbated when specific agencies and human resources addressing fisheries management are lacking (Claudio Baigún, Wetland International and CONICET, Buenos Aires, personal communication; Table 1). While there is a need to strengthen and integrate governance across sectors relying on a shared freshwater resource (Committee on Fisheries 1999; FAO 2009), there is also the need to improve management within the fishery sector (Table 1).

Although the need for international agreements, institutions, and cooperation in governance has been realized for marine fisheries,

Table 1.—Issues and recommendations for improved governance of inland fisheries.

ISSUE: Cross-sectoral integration is lacking in development agendas for freshwater ecosystems.
Recommendations:

- Promote cross-sectoral discussions about the trade-offs and synergies of inland water development and management options that consider the inland fishery sector a partner in resource development in an equitable manner.
- Identify and strengthen platforms and legal frameworks for multistakeholder-based decision making and management.
- Incorporate inland fish and fisheries into the post-2015 sustainability development goals on water issues and include all ecosystem services provided by inland aquatic ecosystems.

ISSUE: Improved governance, especially for shared water bodies, is needed.
Recommendations:

- Establish governance institutions (e.g., river or lake basin authorities) or expand and strengthen the mandate and capacity of existing institutions to address inland fisheries needs in the decision-making processes.
- Commit to incorporating internationally agreed decisions on shared water bodies within national government policies.

ISSUE: Equity and rights of stakeholders must be respected.
Recommendations:

- Apply the principles of the Voluntary Guidelines for Securing Sustainable Small-Scale Fisheries in inland fisheries and, in so doing, recognize, respect, and support governance rooted in traditional customs, rights, and traditional ecological knowledge.
- Protect the cultural heritage of indigenous people and their connections to the environment.
- Ratify and implement the Indigenous and Tribal Peoples Convention of 1989 (No. 169), as well as the Universal Declaration of Indigenous Peoples and other International human rights instruments.

ISSUE: Aquaculture should be an important ally.
Recommendations:

- Adopt an ecosystem approach to fisheries and aquaculture management.
- Recognize the common need for healthy and productive aquatic ecosystems and promote synergies and manage trade-offs among fisheries, stock enhancement, and aquaculture.
- Regulate and manage the use of nonnative species in aquaculture development.

ISSUE: Fishery management is necessary.
Recommendations:

- Implement an ecosystem approach to management of inland fisheries.
- Support effective governmental, communal/cooperative, or rights-based governance arrangements and improve compliance with fishery management regulations.
- Modify or establish fishery and resource management arrangements to protect the productive capacity of inland waters and the livelihoods of communities dependent on the resource.
- Where reduced fishing capacity is called for, establish appropriate social safeguards and provision of alternative livelihoods for people leaving the fishery sector.

ISSUE: Improved communication among users of freshwater is essential.
Recommendations:

- Building from the small-scale fisheries guidelines and other relevant instruments, use appropriate and accessible communication channels to disseminate information about inland fish, fishers, and fisheries to raise awareness about inland fisheries' values and issues, to alter human behavior, and to influence relevant policy and management.
- The fisheries sector should engage other users of freshwater resources and participate in national and international fora that address freshwater resource issues, conflicts and synergies.
- The fisheries sector should invite other users of freshwaters to participate in fisheries management fora.

Table 2.—Sectors and stakeholders that could be involved with governance of freshwater ecosystems; government is a common stakeholder for all sectors.

Sector	Stakeholders
Fishery	Fishers, industry, vendors, and consumers
Aquaculture	Fish farmers, industry, and consumers
Product supply chain	Vendors, processors, distributors, retailers, consumers, and transporters
Energy	Hydroelectric companies and engineers, and municipalities
Agriculture	Farmers, irrigation engineers, and consumers
Forestry	Foresters, agroforesters, timber companies, and consumers
Navigation	Transportation, shipping, and dredging
Land development	Real estate, industry, and consumers
Recreation and tourism	Recreational fishers, hotel operators, hotels, backpackers, and boaters
Conservation	Nongovernmental organizations and the general public
Mining	Mining companies and refining and processing companies
Civil society organizations	The general public
Research	Academia

the recognition is only slowly emerging that a similar system of governance is necessary at a basin scale in transboundary and international inland waters, where fish stocks and water resources are shared (Beard et al. 2011; Table 1). International mechanisms can offer guidance and support for the resource governance that addresses human and ecosystem well-being. For example, the Mekong River Commission (Box 2) was established to provide advice about shared resources of one of the world's most important rivers for inland fisheries (Hortle 2009; Mekong River Commission 2014; Barlow 2016, this volume). Resolution IX.4 of the Ramsar Convention (Ramsar 2005), which addresses the conservation, production, and sustainable use of fisheries resources, stresses, inter alia, that "local, national, and international mechanisms should be established, as appropriate, whereby allocation of essential resources for the protection of aquatic resources and specifically fisheries resources are negotiated among all users of the resource." The European Water Framework Directive (EU 2014) emphasizes the river basin approach for the integrated and coordinated river basin development and management of all European river systems. The framework calls for a comprehensive ecological assessment and classification on the basis of the composition and abundance of the aquatic fauna and flora and taking into account the type-specific reference conditions of the water body.

Currently, numerous regional frameworks, commissions, and lake or river basin authorities provide advice about, or deal directly with, the management of inland waters and living aquatic resources (FAO 2007). However, only 44% of the international basins reviewed are subject to one or more agreements (Table 3); these agreements generally address a variety of issues that may or may not include fisheries. Most of these agreements do not consider ecosystem well-being or fisheries and instead are focused on water as a resource to be managed for irrigation, flood protection, navigation, or hydropower generation (FAO 2007). A more recent review in Latin America revealed that among the 50 international water bodies assessed, fewer than 50% had agreements or mechanisms to address fishery and resource governance issues (COPESCAALC 2011). The Food and Agriculture Organization of the United Nations (FAO) maintains regional fishery bodies that address inland fisheries and aquaculture (FAO regional fishery bodies, www.fao.org/fishery/rfb/search/en). However, unlike many marine groups that have management authority and similar to the Mekong River Commission example above, the FAO inland fishery bodies are purely advisory.

At the national level, it is recognized that, often, institutions are not set up to implement

Box 2. Dams on the Mekong and the Mekong River Commission

Chris Barlow

Governance of the Mekong water resource is divided into the upper (China and Myanmar) and lower reaches (Cambodia, Laos, Thailand, and Vietnam). Balancing national and regional interests is problematic with history showing that national interests generally take precedence over more local interests (Osborne 2009). Policy decisions are often not based on scientific evidence, but rather can be influenced by personal ideology and opportunism. The decentralization of government is a policy in Laos, which has allowed provincial governors to make decisions about the exploitation of natural resources, with implications generally stretching far beyond their provinces. More formally, the 1995 Mekong Agreement signed by the four lower Mekong countries, aims to jointly manage the shared freshwater resources and sustainably develop the river through the Mekong River Commission (MRC); see www.mrcmekong.org). The MRC's mandate is advisory, with the power to implement the MRC's recommendations resting with the four national governments, limiting the effectiveness of the MRC in influencing the management of the Mekong River. Complaints about the perceived ineffectiveness of the MRC to sustainably and equitably manage the resources of the Mekong River may have credence, but the basis for the argument lies more with the governance structure than with technical performance.

Six lessons can be drawn from the experience to date with development of dams on the mainstream of the Mekong River in the lower basin:

1. Decisions about resource use can be unrelated to sustainable resource management, instead reflecting personal ideology and other political influences;
2. Different viewpoints and value judgments by political leaders must be acknowledged;
3. Integrated planning is essential for rational development of natural resources;
4. Decentralization of government hinders sustainable management of natural resources;
5. Technical information is essential to reliable decision making; and
6. Comparison of formal and informal economies, or monetary and nonmonetary values, is difficult and needs to be improved to better inform decisions.

cross-sectoral integration. Recent proposals to the Global Environment Facility have been commended and funded to establish interagency communication entities that will integrate inland fisheries and the people that depend on these into policies on development and management (GEF 2014). Furthermore, the guidance agreed to at the international level for national and regional implementation is frequently disconnected from national and regional decisions that are often implemented in a manner inconsistent with international obligations. In the lower Mekong River, for example, decentralized governance resulted in local decisions being implemented that contravened the international objectives of the Mekong River Commission in regards to conservation of fish stocks (Barlow, this volume; also see Box 2).

Guiding Principles for Effective Governance

The need to improve natural resources governance and to implement an integrated ap-

Box 3. Lessons Learned in the Laurentian Great Lakes Fishery

William W. Taylor and Betsy Riley

Canada, the United States, and a number of sovereign tribal nations border the Laurentian Great Lakes. For centuries, management of fishery resources occurred through multiple and separate management strategies by numerous government agencies throughout the basin. After nearly a century of failed attempts at coordinated management between these governments, the 1940s brought significant ecosystem and fishery changes when alterations of waterways for commerce resulted in the introduction of harmful invasive species into the ecosystem. The resulting demise of commercially valuable native fishes had very serious socioeconomic consequences at the local and regional levels, which provided the impetus for the multiple jurisdictions to cooperate and share information to rehabilitate the fish and fisheries of the Great Lakes. This ultimately culminated in the 1955 establishment of the Great Lakes Fishery Commission (GLFC), tasked with controlling the invasive Sea Lamprey *Petromyzon marinus* and coordinating fishery research and management for fish populations of common concern (Gaden et al. 2013).

Further, the GLFC facilitates accountability and transparency through the 1964 creation of lake committees—one committee for each lake (GLFC, no date; Gaden et al. 2013). These committees provide opportunities for the nations, province of Ontario, states, and tribal (U.S.) governance organizations to meet and exchange information, strategize on regulations, and discuss issues affecting their respective lake and fish stocks of common concern. These committees eventually enabled more effective basinwide cooperation. During the 1970s, the basin's governing institutions began discussions to develop a strategic plan to formalize their agreement to cooperate and apply an ecosystem approach to Great Lakes fishery management. This strategic plan was adopted in 1981 and today provides for the mechanism that has resulted in effective strategies to rehabilitate productive fisheries in these shared water bodies, A Joint Strategic Plan for Management of Great Lakes Fisheries (plan revised in 1997; GLFC 2007; Gaden et al 2013). The success of this forum has been instrumental in rehabilitating Great Lakes fisheries and coordinating fishery regulations across jurisdictional boundaries.

proach that considers all sectors has been discussed for more than a decade (Committee on Fisheries 1999). Although the terminology may have changed, the message has been the same: integrated resource development and management is essential. Several case studies in this paper examine why a freshwater resource governance approach failed while a few assess successful case studies related to fisheries. The majority of case studies, however, do not focus on how to better access and communicate the contributions of inland fisheries to economic, social, and ecosystem well-being. The efforts at freshwater governance instead usually focus on how to best use water resources for the benefit of a specific sector.

This narrow focus and lack of comprehensive vision have undermined fishery management. The focus on a specific economic sector's water needs have oriented resource management toward addressing economic objectives, thus ignoring the management of freshwater resources to support social and environmental demands. The discussion below considers how elements identified as contributing to effective governance can assist in better communicating across sectors

Box 4. International Guidelines Contributing to Food Security and the Role of Inland Freshwater Resources

Rebecca Metzner and Carlos Fuentevilla

International guidelines can provide stakeholders with a framework for creating a participatory governance approach and clarifying stakeholder rights that contribute to food security from terrestrial and aquatic ecosystems. Guidelines regarding tenure rights are expected to reduce the risk of overexploitation, which occurs when groups or multiple individuals claim overlapping tenure rights (FAO 2012). Insecure tenure rights facilitate corruption, as has been shown by the Food and Agriculture Organization of the United Nations (FAO) and Transparency International finding that land administration is one of the most corrupt public sectors in the world, particularly burdening the poor and especially women who make essential contributions to agriculture, fisheries, and forestry in developing countries (Transparency International 2011). *Voluntary Guidelines on the Responsible Governance of Tenure of Land, Fisheries and Forests in the Context of National Food Security* (FAO 2012) noted the need for strengthening and securing tenure rights and developing capacities for stakeholders to fully take charge of their responsibilities to manage their resources sustainably in the long and short terms. Equally as important, the institutions that govern tenure of land, fisheries, and forests need to adapt to the growing pressures on the use of natural resources and change how these resources are used. Governing institutions should also adapt to the growing intensity of competition for natural resources and its effects across sectors. Doing so requires strengthening local organizations and groups (e.g. producers) facilitating the needed intersectoral dialogue and collaboration for enhanced food security and fisheries sustainability (FAO 2012).

The International Guidelines for Securing Sustainable Small-Scale Fisheries (SSF), recently adopted by FAO (2014), identify the rights of the individual and the contribution of SSF to food security and poverty eradication. The SSF promotes the development of initiatives for poverty alleviation, equitable social and economic development, improving governance of fisheries, and promoting sustainable resource use. In particular, the guidelines stress the importance of respecting and realizing human rights and dignity and the need for gender equality, as well as encouraging countries to ensure that small-scale fishers are represented in decision-making processes that affect their livelihoods.

Table 3.—International river basins and management frameworks by continent. Modified from *The State of World Fisheries and Aquaculture* (FAO 2007).

	International basins	Number of basins with international agreements		Inland water commissions with a mandate in fisheries
Continent	(Number)	(Number)	(Percentage)	(Number)
Africa	59	19	32	8
Asia	57	24	42	2
Europe	69	45	63	12
North America	40	23	58	3
South America	38	6	16	6

and, thus, elevating the contribution and importance of inland fish and fisheries in the governance of freshwater resources.

Participation

All stakeholders and sectors should be included in decisions regarding freshwater resources. Inclusive representation is not just ethically good, it has practical applications as well. Incorporating traditional knowledge can offer insights comparable to expert scientific analysis (Chalmers and Fabricius 2007). In addition, bringing in all stakeholders to discuss strategies for sustainable use and enforcement of regulations can be an important factor in helping to improve development of management policies and plans, increasing compliance, and making it easier to adapt regulations to fit changing circumstances (Pomeroy 1994). Last, by involving all stakeholders, it may be feasible to consider, from a social and an environmental perspective, the costs and benefits of proposed activities and implement actions accordingly (FAO 2010a).

Previous efforts to increase stakeholder participation suggest that a forum that ensures representation from all sectors using freshwater is needed when developing policies. To successfully achieve collaborative and coordinated governance, sectors must engage as partners, to effectively influence the outcomes of the governance process. Participation among governments also needs to be improved through, inter alia, the creation and implementation of lake and river basin authorities on shared water bodies (Table 3). Each sector or government also must ensure that they can provide representatives that have the necessary skills and knowledge to engage in the process (Box 5).

Such collaborative approaches can take a long time and require trust between sectors. Additionally, many stakeholders involved in inland fisheries are still not aware about their rights and obligations (Margaret Nakato, World Forum of Fish Harvesters and Fish Workers, personal communication) and, therefore, finding effective participants may be difficult in some areas. Efforts are needed to ensure equity and rights of all stakeholders (Table 1).

Transparency

Transparency ensures that interested parties have access to information and are informed about rules, procedures, impacts of decisions on other sectors, and other relevant information (Heald 2006; Weiss and Steiner 2006; Etzioni 2010; Table 1, Issue: Improved communication among users of freshwater is essential). Transparency is achieved through access to reliable information requisite for informed discussions about the synergies and trade-off opportunities existing among freshwater sectors (Vishwanath and Kaufmann 2002). Transparency requires clear communication; especially challenging is communicating information in a timely manner and in a format that is easily understandable to policymakers and stakeholders (Lynch et al. 2011). If stakeholders either do not have access to the information or the information is incomplete or not understandable, transparency is not truly achieved. Accurate communication of the results of discussions, as well as the success or failure of management actions, is an essential component of transparency. Providing a transparent process also attracts participation by informed stakeholders and facilitates implementation and enforcement by having stakeholders that are supportive of decisions (McGarrell et al. 2013). Improving communication and encouraging cross-disciplinary integration may enhance transparency by reducing the challenge of accessing and understating information from the various sectors (Box 5) and engaging outreach and communication specialists.

Accountability

Accountability is a critical aspect to ensuring that governance processes and management actions result in the agreed outcomes. Accountability must exist between stakeholders and those charged with the responsibility to govern and manage freshwater resources (Béné and Neiland 2006). Accountability requires clear, measureable, and enforceable objectives related to all outcomes and allocation

Box 5: A Sliver of Water—Overcoming Barriers to Cross-Sectoral Governance

John Fazio, Jim Ruff, and Nancy J. Leonard

A portion of the millions of acre-feet of water in the Columbia River basin's hydrosystem are currently allocated for mitigating hydrosystem impacts on fish and wildlife. This sliver of water, called the water budget, averages about 10% of the hydrosystem's energy generation and ranks third in priority when making hydrosystem operating decisions: flood control being first and emergency power generation being second. Recognizing the need and achieving cross-sectoral agreement to allocate water for fish and wildlife affected by the hydrosystem's operations is an impressive accomplishment. Prior to the 1980s, Federal Columbia River Power System operators officially recognized two water sectors in their decision-making process, agricultural irrigation and hydroelectricity generation (USDOE et al. 1995; J. Fazio, 2006 memorandum to Northwest Power and Conservation Council members, on multiple purposes of the Columbia River hydroelectric system). The U.S. Army Corps of Engineers has flood control jurisdiction over all Columbia River reservoirs in Canada and the United States (Fazio, memorandum). Coordination of the Columbia River Basin's freshwater did not explicitly consider fish and wildlife. This omission had been attributed to the tribes' and the fish and wildlife agencies' lack of political support and understanding of the hydrosystem's power system planning processes and operations. Thus, the planning and the operation of the hydroelectricity system reduced flows in a manner that degraded the aquatic habitat for fish, increased migration time for juvenile salmon, and exposed them to higher predation rates (NPCC 1982). The Northwest Power Act of 1980 gave fish and wildlife needs "equitable treatment" with other purposes, particularly hydropower. To address the lack of understanding, it was necessary for the fishery management agencies and tribal representatives to speak the language of the power system and to speak with one voice. The 1982 and 1984 Columbia River Basin Fish and Wildlife Program provided the policy guidance about how to integrate fish flow requirements in power system decisions. This guidance ensured that fisheries experts are included in the hydrosystem planning and operation process by providing the needed resources and political support. The combination of efforts to improve juvenile salmonid survival during the 1980s and 1990s, including changes in water flow, installation of both surface and screened bypass systems, and increased spill have all contributed to improved conditions for fish and higher juvenile survival (Williams et al. 2001; Muir and Williams 2012).This river management approach, applied since the 1980s, appears to be successful as it has continued to be applied for the past three decades with all water sector needs being met somewhat adequately, although not to the full satisfaction of each sector (see Box Figure 5.1 below).

Box continues

consequences. As such, there needs to be sufficient information to determine whether policies and resultant actions contribute towards achieving these objectives. It is also important to be clear about who is accountable to whom, in what ways, and in what time frames actions and results will be reported. However, accountability often remains undefined and vaguely alluded to in governance processes (Béné and Neiland 2006).

Box 5. Continued

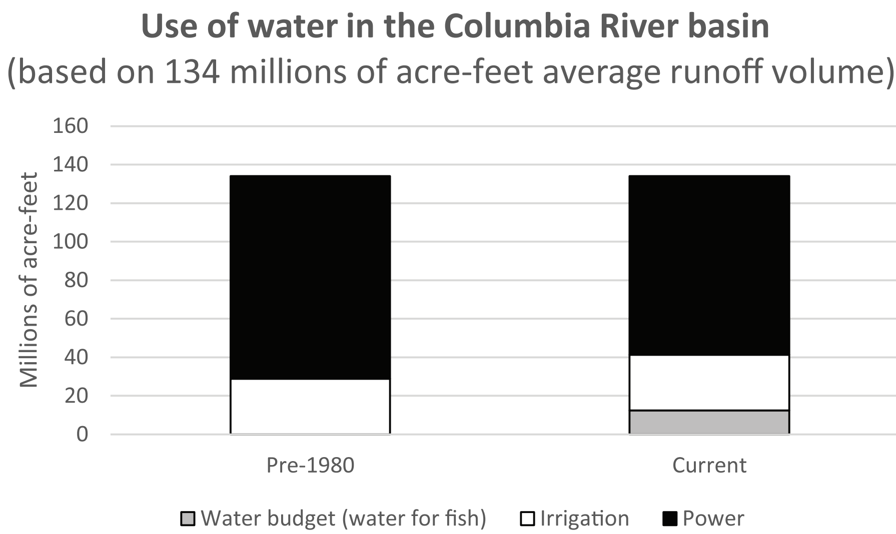

Figure 5.1.—Change in water allocation amount irrigation and hydroelectricity (power) generation following the implementation of the water budget. The water budget allocated water for fish needs, such as during salmon migration.

Governance of freshwater resources often has clear processes by which the governing institutions account for their decisions to agricultural and hydroelectricity stakeholders (e.g., why certain amounts of water or electricity are made available at a given price). Conversely, accountability for freshwater allocation decisions impacting the fishery sector has tended to remain nebulous. Part of the problem with making institutions accountable is the difficulty in ascertaining the impact of changes in freshwater quality and quantity on fisheries, aquatic species, and their habitats. For the governance process to work effectively, governing institutions must take measures to be accountable to all freshwater sectors impacted by their policies and decisions (Boxes 1 and 6).

Access, human rights, and equity

Good governance should ensure fair and equitable access to resources and to the benefits derived from the use of those resources (Onyango 2000). A human-rights-based approach can help clarify and organize governance issues related to food security and nutrition by (1) providing for basic rights, primarily the right to food (e.g., the 1948 International Bill of Human Rights, the 1979 Convention on the Elimination of All Forms of Discrimination against Women, and the 2007 United Nations Declaration on the Rights of Indigenous Peoples); and (2) the right to access resources (e.g., FAO 2012).

As land and water resources are developed and thereby made more valuable, access to those resources is often given to new users at the expense of traditional users (e.g., in Bangladesh, valuable fisheries were created in oxbow lakes, but traditional fishers were prevented from accessing the water bodies [Nurul Islam et al. 2014]). Addressing fair and equitable access to a fishery, however, is not sufficient; it is

Box 6. Accountability through Flexibility and Partnerships in River System Planning

Kristin Meira

With so many activities and interests on the Columbia River system (USA), governance occurs to varying degrees at local, state, regional, national, and international levels. Freshwater sectors, including agriculture, irrigation, hydroelectricity, fisheries, have struggled with how to assess and report to their stakeholders about how they are utilizing freshwater while improving conditions for endangered salmon and steelhead (anadromous Rainbow Trout *Oncorhynchus mykiss*). The common thread woven through these layers of oversight is the desire to hold accountable all those involved in decisions related to river system activities for impacts on northwest fish populations.

In 2009, the federal agencies responsible for implementing and reporting on listed species included an Adaptive Management Implementation Plan (AMIP) as part of the Federal Columbia River Power System (FCRPS) biological opinion. The AMIP was the result of an intensive review of the 2008 biological opinion, including listening to the views of parties to the FCRPS biological opinion litigation, fisheries management agencies and independent scientists, and consideration of points raised by the judge overseeing the FCRPS biological opinion U.S. District Court case. The AMIP serves as an accountability tool that consists of biological objectives and indicators to detect and report on declines in abundance of salmon and steelhead listed under the Endangered Species Act. The AMIP facilitates implementation of a rapid response set of contingency actions to address unexpected declines in abundance. The goal is to create a plan for operating the river system that is flexible enough to respond to changing conditions. The plan also provides guidance to improve efforts to track and detect climate change and its effects on listed salmon and steelhead species. This plan also considers other factors that could emerge during the 10-year life of the biological opoinion that may impact the abundance of listed species.

These biological indicators and contingency actions added a level of transparency and accountability by requiring agencies to more frequently report the status of the endangered salmon and steelhead and clearly describe what course of actions will be taken if a significant decline in abundance is detected. In addition to heightened monitoring and enhanced planning, more collaboration is occurring on the Columbia River than ever before. In 2008, sovereign tribes signed landmark agreements with several U.S. states and federal agencies. The Columbia Basin Fish Accords cleared the way for US$900 million in salmon restoration projects throughout the Columbia River basin over 10 years (CRITFC 2008). It also signaled improved partnership between parties that had previously been on opposite sides of the courtroom. In the first 5 years of their work, the Columbia Basin Fish Accords partners delivered new spawning habitat, protected or improved more than 175,000 acres of fish and wildlife habitat, and protected more than 35,000 acre-feet of water (Columbia River Basin Federal Caucus 2014a, 2014b). These benefits demonstrate the progress that can occur when parties are able to work together rather than meet solely in litigation.

equally important to ensure fair and equitable access to the water where fish live, to the land where fishing activity takes place, and to the markets where they are sold.

Governance processes should treat men and women equitably. Men and women often play different roles in the fisheries, with men more involved in harvest and women more involved in postharvest activities (Weeratunge et al. 2010). In particular, attention needs to be given to how the loss of access to inland fish resources along the complete production chain impacts a community, especially the vulnerable and marginalized people often in small-scale inland fisheries (e.g., HLPE 2014).

Human rights are incorporated into governance aspects through, *inter alia*,

- participation,
- accountability,
- nondiscrimination,
- transparency,
- human dignity,
- empowerment, and
- rule of law.

The above elements, named PANTHER (FAO 2014e), focus on the underserved groups (such as small-scale producers, indigenous people, and women) whose food security is most vulnerable to changes in inland freshwater fisheries (Box 7).

Ecosystem well-being

The cumulative costs to aquatic ecosystems and human well-being can be quite high when ecosystem well-being is not considered in governance of freshwater resources (Table 3). Costs to the ecosystem include species extirpations, deterioration of aquatic habitat, and loss of ecosystem services. Expensive restoration efforts are a long-term cost to human well-being. Human health costs include reduced availability of protein and costs of land-based agricultural and aquacultural projects (MA 2003). Often decisions that result in these costs are based on flawed economic analyses, which calculate the monetary benefits of large-scale development while improperly considering the full range of costs and loss of ecosystem services. This likely occurs because the benefits of the development are easily calculated as the net income of a single or small number of businesses while the costs in terms of loss of ecosystem services are externalized and dispersed between the environment and society.

Sustained ecosystem well-being needs to be a critical outcome of governance processes (Pasqual-Fernández and Chuenpagdee 2013) as it is the basis for production for freshwater fish and fisheries. The importance of ecosystem well-being to social and economic well-being is gaining attention at higher levels of governance (MA 2005; FAO 2009). Indigenous peoples have long recognized that the unique relationship between land, water, and species is central to sustaining their culture, governance, communities, and economies (Box 7). Numerous international organizations have developed instruments and criteria for sustainability and, thus, ecosystem well-being. Some examples are the FAO Code of Conduct for Responsible Fisheries (FAO 1995) and more specialized instruments such as ecolabeling guidelines for inland capture fisheries (FAO 2010b) and the aquaculture certification guidelines (FAO 2012b). Ecosystem well-being, however, needs more attention in the governance of freshwater resources, including fisheries.

Capacity

If there is insufficient capacity to develop and implement policies and support the institutions needed for management of freshwater resources, including fisheries, it is unlikely that the desired outcomes will be attained (e.g., upper Volga case study, Box 8). For a cross-sectoral governance process or institution to succeed, it needs to have adequate knowledge, human and financial resources, and authority for implementation (Béné and Neiland 2006; Schechter and Leonard 2008). To achieve adequate capacity, the role and needs of the public sector, private sector, and civil society organizations all need to be considered, and communications and linkages among them enhanced. Improving economic growth and human development (Sako 2003) may also improve capacity for cross-sectoral governance, as long

Box 7. Role of Rights Holders in Fisheries Governance

PAULINE TERBASKET AND JAY JOHNSON

A strong role for local title and rights holders in the governance of fish, fisheries, and their watersheds is often a critical determinant to ensuring the sustainability of fisheries and aquatic ecosystems. These key rights holders can provide valuable knowledge to ensure the sustainability of the natural resources, and their support is necessary for successfully implementing and enforcing actions that provide for sustainable fisheries. When rights holders and fishers are not meaningfully included in governance structures, governance that ensures sustainable outcomes is not and cannot be effective.

The legal title and rights of the Okanagan (Syilx) Nation to its fish and territory, including the transboundary Columbia River, are increasingly recognized given its status as the local historical indigenous community. The traditional knowledge and the deep and unique relationship of the Okanagan Nation to the land, water, and species that are central to sustaining its culture, governance, communities, and economies have largely been ignored and marginalized by Canadian federal and provincial governing institutions. One of the biggest fisheries tragedies faced by the Okanagan Nation was the devastation of the salmon stocks that are the lifeblood of the indigenous communities. Dam construction in the Columbia River basin and the U.S.-based hydroelectric industrialization of the Columbia River reduced salmon abundance and prevented salmon passage to access the upper reaches of the Canadian Columbia River system. This loss of the salmon in key parts of the Columbia River remains a historical injustice. Efforts to address some of these past injustices includes U.S. legal challenges based on indigenous rights to restore the role of tribal and First Nations groups to a stronger governance role in the river system.

These legal and governance successes, combined with traditional restoration prescriptions, have begun to restore the habitat and environmental conditions necessary for salmon survival in parts of the Columbia River system. While the upper reaches of this river salmon remain blocked, intervention and restoration activities by the Okanagan Nation have led to an increase in the annual Sockeye Salmon *Oncorhynchus nerka* returns in the Okanagan river portion from the near extinction numbers of 3,500 in 2005 to more than 300,000 Sockeye Salmon in 2015. The Okanagan Nation, in collaboration with U.S. tribal partners who exercised their indigenous treaty rights first through the federal courts (Boldt and Redden decisions, U.S. Supreme Court, 1975 and 2005) and then through negotiations with all parties involved, resulted in increased seasonal water flows over dams, increased support and recognition for indigenous peoples informed habitat restoration projects, and better fish passage structures, all of which are critical for salmon survival and restoration. Today, due to indigenous leadership, collaborative fisheries management, and a broader social demand for environmental sustainability that incorporates the traditional knowledge of the people who are most affected by these resources, the salmon are returning! Recent successes, such as the salmon returning from near extinction in other portions of the Okanagan Nation's territory, are providing hope that with great effort and collaboration, the historical injustice of the loss of salmon in the upper portions of the Columbia River will too be overcome.

Box 8. Incorporating Local Knowledge and Rights into Fisheries Governance

Dmitry Pavlov and Bakary Kone

Local knowledge and recognition of existing rights are crucial factors in effective fisheries governance. When these are not appropriately considered, it can be very difficult to sustainably govern and safeguard existing fishery resources, as the following examples from the upper Volga river (Russia) and inner Niger delta (Mali) illustrate.

Upper Volga River

In 2007, commercial fishing was banned in two of the upper Volga reservoirs. It was expected that a decrease in the fishing pressure would result in the recovery of valuable fish stocks. However, after 6 years, not only had the stocks not recovered, they had continued to decline. The main reason for this was a change in access, which changed how fishers approached their fishery resources. Historically, the fishing grounds were granted to commercial fishers on a long-term basis. These fishers were usually organized in some form of collective enterprise (e. g. cartels or family companies), which treated the fishing grounds as their own property and protected fish stocks in collaboration with the state fishery authority. Forms of collaboration varied from patrolling the waters to informing the guards about illegal fishing. The ban of commercial fisheries resulted in the lack of this protection, with the state fish guard unable to provide efficient control of poaching (D. Pavlov, personal observations).

Inner Niger Delta

In the inner Niger delta (IND) of Mali, fisheries diversity and harvest are controlled by the flood regime. Traditionally, the maitre d´eau of the Bozo was the water master in the inner Niger delta (Wymenga et al . 2012). The maitre d´eau is at the center of the group of fishers and has three essential rights: (1) annually renewing the sacrificial pact with the spirits of the river, (2) deciding on the establishment of the largest permissible annual fisheries, and (3) regulating the practice of fishing. The maitre d´eau owns specific fisheries (to which he has an exclusive right or privilege). The disruption to the traditional governance approach, due to numerous factors, including the conquest of the IND by immigrants and occupiers, the centralization of power in the management of resources by the national government, and the loss of powers of traditional managers of natural resources such as maitre d´eau of the Bozo, has severely impacted the sustainable management of this region's natural resources. Currently, an effective mechanism is lacking for coordination of water management across scales (local, regional, and national) and between upstream (hydropower) and downstream (fishers) users of freshwater resources. Thus, dams on the upper portion of the Niger, which control the water level, negatively impact fish production downstream in the IND area. Additionally, there is no mechanism that allows downstream users to have a voice when decisions concerning upstream (dam) water use are made. The main constraints facing fisheries governance in the IND are that (1) traditional maitres d´eau are no longer involved in decision-making processes, with their authority instead being transferred to local mayors; (2) there

Box continues

Box 8. Continued

is an increasing number of fishers; (3) prohibited fishing techniques are being used; and (4) there is little implementation and enforcement of fishery laws and regulations; all of which has led to a reduction in the sustainability of IDN fishery resources (see also Wymenga et al 2002, 2012; Zwarts et al. 2005; Beintema et al. 2007; Kone 2012; and van Beukering et al 2013).

as the above aspects of good governance are maintained.

Opportunities for Improvements

Overall, global, national, regional, and local efforts to improve the governance of inland fish, fisheries, and freshwater resources need to be strategic and comprehensive in breaking down sectoral segregation. There is general agreement that opportunities for improvement in freshwater resources governance exist when applying an inclusive landscape and ecosystem approach (Box 4; Liu and Taylor 2002; FAO 2009, 2013). These discussions and recommendations, however, rarely explore how this approach can be practically implemented (e.g., ISAB 2011). Areas of opportunities and potential solutions, including recent actions that may facilitate progress, are highlighted below.

Strengthening governance of the fisheries sector

More holistic approaches to governance of the fishery sector are needed, involving fisher groups and other freshwater sectors, as well as participants along the entire fisheries value chain (e.g., harvest, processing, marketing, and distribution; Table 1). As guidance approaches and tools for effective cross-sectoral governance are developed, there will be opportunities to implement and improve current governance, as long as policymakers determine that it is worthy to invest in these improvements. For example, the FAO Committee on Fisheries recently produced voluntary guidelines to improve the governance of small-scale fisheries, which will help policymakers make informed decisions, avoid conflict within the fishery sector, and ensure responsible use of freshwater resources (Box 4; FAO 2014b). Improvements include well-designed fisheries governance processes, better management across all inland fisheries, better integration along the entire fisheries value chain from capture to consumption, and, last, governing fisheries within its larger ecosystem context. Existing governance processes differ in their adequacy to govern inland fish and fisheries, irrespective of the type of fisheries (commercial, recreational, subsistence small-scale). In many South American river fisheries, for example, a centralized management framework supports a harvest-oriented market approach directed to maximize economic returns through intensive exportation fisheries (Baigún et al. 2016, this volume). This framework in South America does not recognize management issues relating to the conservation of aquatic resources, improving socioeconomic benefits, and welfare of fishing communities. There are some examples in the Amazon River basin of successful management for multiple outcomes (Baigún et al., this volume), and these approaches need to expanded to other watersheds and be integrated as part of regular management programs more widely.

Current governance regimes have a tendency to partition fisheries governance based on the type of fisheries instead of applying a holistic governance approach. For instance, governance regimes have tended to partition fishing areas (i.e., zoning) between small-scale fisheries and larger-scale fishing operations, but these zones are weakly enforced and do not resolve the inability to limit access and fishing effort (Committee on Fisheries 2011). Improving governance for all fisheries requires understanding and consideration of the pressure exerted on the resource by fishers so that one group of fishers is not detrimentally impacted by another. Achieving this level of comprehensiveness will contribute to achieving economic, social, and ecosystem well-being (FAO 2014b).

Fishers, markets, producers, and consumers are often considered separately in governance structures with little consideration for how these interrelate. Considering all fishing operations and the entire fisheries value chain will enhance the fishery sector's ability to communicate effectively about the overall value of fisheries and the requirement for freshwater during the development of future allocation policies. The expected benefits of applying this integrated approach to freshwater fisheries mirror those for marine fisheries, which facilitate fishery sustainability by incorporating reliable traceability systems that allow tracking fish from harvest to the market (UNEP 2009).

Valuation of inland fisheries

Understanding the value of inland fisheries to societal and human well-being is an aspect of inland fisheries that needs to be improved (Table 1). The current obstacles to determining and communicating inland fisheries values partially arises due to lack of data and the challenge in communicating the value in terms meaningful to policymakers and the public.

Inadequate monitoring of small-scale fisheries is the norm in many countries. As a consequence, there is a paucity of data about the status of stocks, numbers of fishers, and the socioeconomic values of the resource (see Economic and Social Assessment and Biological Assessment themes, this volume). The lack of quantitative information leaves the fishing sector in a weak negotiating position compared to other sectors (e.g., hydropower, irrigation, and navigation) that can more easily document the economic contributions of their industries. Inland fishery management agencies would benefit greatly from rigorous studies that demonstrate the multiple values of their fisheries.

Different approaches to valuing inland fish and fisheries have included determining

- the economic value of the recreational the fishing industry (Southwick Associates 2013),
- the nutritional contributions of inland fish (Thilsted 2013; Roos 2016, this volume);
- the ecosystem services, including the role of fish in food webs (e.g., supporting piscivores such as the grizzly bear; Johnson and O'Neil 2001);
- the historical and cultural values (Box 7);
- the scientific value of fish (e.g., as laboratory models in toxicity and genetic studies; Ribas and Piferrer 2014); and
- the nonfood commercial value of fish (e.g., in identifying antifreeze proteins that may contribute to biotechnology advances; Yamashita et al. 2014).

Depending on the situation, a combination of these approaches may be communicated effectively to policymakers.

Working together

Efforts to improve the governance of inland fisheries and freshwater resources need to be strategic and comprehensive (Table 1). There are important international partners for addressing water and food security that the fishery sector should engage, including, inter alia, the World Water Forum, the Water Governance Facility, the Global Water Partnership, the Organization for Economic Cooperation and Development, the Initiative on Water Governance, and the World Water Council. An FAO-commissioned report (McInnes et al. 2014) that evaluated institutions for their potential to effectively engage inland fisheries issues revealed an additional 10 entities whose opportunity for action and relevant mandate would indicate that strategic partnerships with the inland fishery sector would be beneficial (Figure 1). Sectoral approaches will be difficult to change; the above report further stated that FAO needed to better integrate inland fisheries into its own program of work.

Embracing a diversified livelihood and conservation

In many developing areas with inland fisheries, integration of food production and conser-

		Priority or opportunity for action	
		Low	High
Relevance of mandate	Low	• UN Convention to Combat Desertification • UN Framework Convention on Climate Change • UN Convention on the Law of the Sea • Antarctic Treaty • Global Earth Observation • Basel Convention • Rotterdam Convention • UN Environment Programme Global Plan of Action • Intergovernmental Panel on Biodiversity and Ecosystem Services	• UNESCO Man in the Biosphere • Sustainable Development Goals • Global Environment Facility • Forestry Sector
	High	• Helsinki Convention • UN Non-Navigable International Watercourses • IUCN Freshwater Fish Specialist Group • International Collective in Support of Fish Workers • Stockholm Convention • UN Environment Programme	• Food and Agriculture Organization of the UN • Convention on Biological Diversity • Ramsar Convention • Convention on Migratory Species • Convention on International Trade in Endangered Species of Fauna and Flora • UN Water • The Economics of Ecosystems and Biodiversity • Voluntary Guidelines on the Responsible Governance of Tenure of Land, Fisheries and Forests • Water-food-energy nexus • Wider water fora

Figure 1.—Prioritization of various intergovernmental instruments, mechanisms, processes, and organisations for engagement by the inland fishery sector. (From R. J. McInnes, RM Wetlands & Environment, N. C. Davidson, Wetlands Internationaland D. Coates, Secretariat of the Convention on Biological Diversity, unpublished report).

vation activities are vitally important (Table 1). Increases in food demand may be met by intensifying domestic production, which may threaten aquatic biodiversity that is extremely important for local food supply and livelihoods (Bharucha and Pretty 2010). In areas where water and terrestrial resources uses merge, as happens in most floodplains, it is critical to maintain ecological processes to assure that fisheries, agriculture, cattle ranching, and so forth can be developed in a sustainable way according to natural conditions. In the Paraná Delta, for example, increased intensive land-use practices supported by development of embankments and levees have promoted changes in land use that are negatively affecting floodplain fisheries (Baigún et al. 2008). In the Lake Chad basin where households are actively involved in fishing, farming, and herding (Béné et al. 2003), fishing is a major activity in all households at all income levels. Agricultural landscapes are being replaced by ecoagriculture landscapes, where biodiversity conservation is a stated management objective in rural development (Scherr and McNeely 2008). This change is beginning to occur in policy discussions such as in Laos, where Bharucha and Pretty (2010) advocate the integration of conservation policy, food policy, and agricultural policy to recognize and preserve the importance of wild foods. Recognizing this reality, new approaches to governance and resource management must acknowledge and address the numerous interrelated aspects of food production and conservation activities in many rural communities

The Future and Recommendations for Better Governance

The first United Nations water development report stated that the "water crisis is essentially a crisis of governance" (UNESCO 2003). This crisis directly impacts inland fisheries and freshwater ecosystems. The diffuse nature of inland fishery resources and the numerous users of freshwater ecosystems render achieving effective governance a complicated and difficult goal. Application of the ecosystem approach to fisheries has generally been focused on marine fisheries and has often only been considered to be a sectoral approach (i.e. only dealing with issues under the control or influence of the fishery sector; Box 3). Efforts to include consideration of inland fisheries in cross-sectoral ecosystem based approaches have not been overly successful (UNEP 2014). Nevertheless, these efforts are crucial as the socioeconomic contribution of inland fisheries to poverty alleviation and livelihoods must be understood (Béné et al. 2007). An ecosystem-based approach is needed for multisectoral integration, effective governance, and continued contribution of inland fisheries to food and nutritional security. If this approach is not adopted, history has shown that the fisheries and freshwater resources deteriorate to the point of significantly reduced benefits being provided, including a decline in food security for communities.

Achieving cross-sectoral, integrated governance of freshwater ecosystems and their fisheries will require fishery managers, policymakers, and ministers to engage broader, more multidisciplinary audiences and to form new partnerships (Box 5; Table 1 Issue: Cross-sectoral integration is lacking in development agendas for freshwater ecosystems). The FAO Committee on Agriculture convened a recent session on water governance for agriculture and food security, wherein terrestrial agriculture presented a case for improved governance. The fishery sector was not represented (D. M. Bartley, personal observation) but obviously would have been a valuable participant in this intergovernmental discussion. Clearly, there is a disconnect between each sector's impact on others, further emphasizing the need for a new integrated governance structure and a more interdisciplinary work force that can effectively communicate to multiple sectors the cost and benefits of policy decisions.

A first step to achieve this integration may involve having the fishery sector engage important international partners that address water and food security. The fishery sector, to engage with other sectors, will want and need justification to approach these other sectors. The donor community that funds research, as well as development and conservation activities, is recognizing that integration among sectors is important and is taking action that encourages integration in the work that the donor community funds (GEF 2014).

While characteristics of good governance may be easily outlined, transitioning to such a status is difficult and requires clear perspectives and a properly sequenced process (Committee on Fisheries 2012). Fishers and fishing communities need to be consulted, fully engaged, and aware of the various approaches to manage fisheries and of their own options for diverse livelihoods over the shorter to longer terms. Other water resource users must become aware of the value of inland fishery resources. Communities lacking current or emerging basic needs (e.g., adequate food and water) are the most in need of good governance but may be unable to engage in the governance processes unless empowered to do so and have their other needs effectively addressed on a short and long-term basis.

Short-term transition measures

Any endeavor to improve fisheries and inland freshwater resources has to commence with intense consultation and awareness-raising with the local community, policymakers, and practitioners (Table 1, Issue: Improved communication among users of freshwater is essential). To establish the needed critical information about the fishery, the fishers and concerned communities must be involved in the process to build trust, confidence, and ownership that will support improved governance. Fisheries agencies will need to cooperate with other government departments, such as environment, health, education, and water, and meaningfully engage with the private sector, nongovernment organizations, and community organizations. For the short term, identifying management measures that can generate quick improvements in terms of cost savings, increases in food security, livelihoods and societal prosperity are a priority. Demonstrating the benefits of this transition early in the process is important to get widespread support. In the inland fisheries sector, the priority short-term measures should address reducing capacity where this is an issue and should focus more on engagement of other sectors to improve fish production and ensure access to food and livelihoods (Committee on Fisheries 2012).

Medium- to long-term transition measures

Effective governance of inland freshwater resources may require applying a system that formalizes allocation among sectors (Table 1). This change will take time to establish the appropriate legislative framework. The process for this change will need to be based on a thorough evaluation of the strategy for social and economic development of the sectors using freshwater. For inland fisheries, allocation among the various users of freshwater is critical. Establishing allocations among users may require not just an amendment of the fisheries laws and regulations, but also political engagement for additional reform, such as the country's constitution. This will also require recognition of possibly competing interests between industrial and smaller-scale sectors and between local, national, and international aims. In parallel to legal reform, local and provincial fisheries and water management plans may also need to be developed or altered through a participatory, interdisciplinary, integrated, and inclusive planning process. Central to the above concepts is the need to develop and apply a holistic approach to fisheries governance (Garcia and Cochrane 2005) to promote strong stakeholder involvement and adaptive management as main pillars for long-term successful governance.

Achieving these medium- to long-term transition measures may aid in rebalancing resource distribution, which, in many developing countries, favors nonfisheries sectors. This rebalancing by allocating resources towards inland fisheries could result in aiding (1) small-scale producers who would directly benefit from improved access to resources that contribute to poverty reduction and food security, and (2) other sectors by reducing conflict and improving the efficiency, profitability, incomes, and livelihoods of the workforce. Likewise, in many cases, fishing capacity must also be managed and, in some cases, reduced or redistributed among subsistence, commercial, tribal, and recreational fishing.

Outlook into the future

Improved governance in inland freshwater resources and inland fisheries cannot be pursued in isolation of other social, economic, and political processes. Indeed the case for reform needs to be seen and implemented within that construct. Thus, the first task is connecting the fishery sector, its people, and its issues, with broader development processes at local, regional, and national levels. It is equally important to ensure adequate recognition of the fishery sector's role, and build the knowledge base and political capital needed to bring about positive and sustainable change to freshwater resources governance. These connections should also serve to raise awareness about the strong relationship between the different human impacts that occur at local, regional, and basin scales and their effects on fisheries resources. Of particular concern is how the hydroelectricity sector can affect fluvial ecological integrity, particularly where large dams and reservoirs are planned that could lead to severe fishery habitat degradation.

The international development community can assist in transiting to good governance by recognizing the cross-sectoral nature of the problem and its solutions. The fisheries sector must realize that engagement of the other users of freshwater is mandatory (Figure 1; Box 1; Table 1). For this increased collaboration to succeed, significant developments are needed in building partnerships and exploring effective mechanisms of change and trust-building supply-and-value chain into governance structures so that incentives are effectively reinforced and information is communicated appropriately.

We propose recommendations in six key areas that we believe are important for improved governance and responsible management of inland fisheries (Table 3). The path towards better governance of inland freshwater resources is clear. The challenge will be in getting cross-sectoral support to follow that path and produce leaders and policymakers who embrace cross-sectoral collaboration and sectoral reform where needed. The experience with integrated resource management, whether called an ecosystem-based approach, integrated water resources management, or integrated coastal area management, has not been overly positive (Hefney 2013). Even at FAO, the United Nations' specialized agency with fisheries and aquaculture, forestry, agriculture and natural resource management departments, the integration of sectors has been lacking (McInnes et al. 2014). Although difficult, integrating the various sectors into an equitable, productive, and sustainable system of governance for inland fisheries and freshwater resources will be essential for the livelihoods of millions of people dependent on freshwater ecosystems.

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Conflicting Agendas in the Mekong River: Mainstream Hydropower Development and Sustainable Fisheries

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Abstract.—Development of hydropower dams on the mainstream of the Mekong River is highly contentious, particularly in Laos where two mainstream dams are under construction and another seven are planned. The debate revolves predominantly around the economic development associated with increased electricity supply and sales, versus the livelihood disruption resulting from the degradation of the traditional uses of the river (primarily fisheries) and other ecosystem services. Assessment of policy and management indicates six lessons relating to the governance of the Mekong and potentially other large transboundary rivers. These are that decisions about resource use can be unrelated to resource management, different public viewpoints and value judgments by political leaders must be acknowledged, integrated planning is essential for rational development of natural resources, decentralization of government hinders sustainable management of natural resources, technical information is essential for decision making and assessment of trade-offs, and difficulties in comparing monetary and nonmonetary values encumber policy development.

The Geography and Traditional Use of the Mekong River

The Mekong River is one of the world's great rivers. It extends about 4,900 km from the Tibetan Plateau in China to its mouth in southern Vietnam (Liu et al. 2009). It traverses six countries—China, Myanmar, Laos, Thailand, Cambodia, and Vietnam. For most of its length, the river flows through mountainous terrain before entering the lowlands of Cambodia and Vietnam, where it forms one of the world's great deltas. In China, the Mekong is constrained by a comparatively narrow river valley. As the river exits China and Myanmar, its catchment broadens and numerous large tributaries arise on the eastern side, in the Annamite Range of Laos, Vietnam and northeastern Cambodia. Several large tributaries also flow in from Thailand to the west of the mainstream. Flow is predictable and highly variable seasonally; average monthly discharges reach a maximum of 40,000 m^3/s in September and a minimum of 2,000 m^3/s in April (Adamson et al. 2009).

Approximately 70 million people live in the Mekong catchment, with about 75% living in rural areas. Poverty is endemic, although the poverty indices vary between rural and city dwellers and among countries. Rural areas, especially in Laos and Cambodia, are characterized by a lack of paid employment opportunities, food insecurity, inadequate infrastructure and services, and a high dependence on the natural resources of the river and adjacent lands (MRC 2010).

The capture fishery of the lower Mekong River basin (that is, downstream of China) is the largest freshwater fishery in the world, with an annual yield of approximately 2 million metric tons per year (Hortle 2009). To

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put this in perspective, it is about 2% of the global fish catch, marine and freshwater combined. Freshwater fish and other aquatic animals constitute averages of 48, 47, 80, and 59% of the animal protein consumed by people in the Mekong basin regions of Laos, Thailand, Cambodia, and Vietnam, respectively (Hortle 2007); that is, consumption of freshwater fish and other aquatic animals nearly is equal and often exceeds that of all other meats combined.

Other traditional uses of the river include navigation, irrigation, and horticulture on the banks of the river (river gardens). Importantly, the river holds considerable cultural value for the many communities in its catchment.

Governance of the Mekong

Governance of the Mekong water resource is, in practical terms, divided into the upper and lower reaches. The upper reach is in China, where governance is comparatively straightforward as no other countries share that stretch of the river.

The lower Mekong countries signed the 1995 Mekong Agreement, so forming the multijurisdictional Mekong River Commission (MRC), with the intent of jointly managing the shared water resources and sustainable development of the river (see Mekong River Commission for Sustainable Development, www.mrcmekong.org). The MRC Secretariat (MRCS) administers the technical work of the agency. Its mandate is advisory. The power to implement the MRCS' recommendations rests with the four national governments. The distinction between the facilitative and advisory role of the MRCS and the implementing authority of the four member governments is often not appreciated by commentators and has led to criticisms of the MRCS' performance. Complaints about the ineffectiveness of the MRCS to sustainably and equitably manage the resources of the Mekong may have credence, but the basis for the argument lies more with the governance structure than it does with technical performance. The highest arm of the MRC is the council, which is comprised of water or natural resource ministers from the member governments. Balancing national and regional interests is problematic for council members, with history showing that national interests generally take precedence (Osborne 2009).

There are other less-formal interests that variously impact the governance of the Mekong River. The geopolitical interests of China extend pervasively into political influence and economic integration with neighboring countries. Decentralization of government is a policy in Laos, which has allowed provincial governors to make decisions about exploitation of natural resources with implications stretching beyond their provinces. Policy decisions are often not based on evidence and can be influenced by personal ideology and opportunism. In the context of the Mekong, evolution of policy is constrained in political environments in which international commentary can be seen as encroachment on hard-won state sovereignty and domestic criticism can be construed as unpatriotic (Dore and Lazarus 2009).

Hydropower Development and Inland Fisheries

China has completed three large dams on the Mekong and a further five are being built or are planned. These dams have major impacts on hydrology and completely block fish migration in the upper Mekong. Below the China–Laos border, the main impacts of the dams are on dry-season flows, which are increased as a consequence of stored water being released through hydropower generation, and on suspended sediment, which is trapped by the dams.

On the mainstream in the lower Mekong basin, nine high-level dams are planned in Laos (construction has started on two, the Xayaburi and Don Sahong dams), and a further two are planned in Cambodia. Studies by the MRC (e.g., Barlow et al. 2008; Halls and Kshatriya 2009; Dugan et al. 2010; ICEM 2010) and others (e.g., Roberts 1995; Baran and Myschowoda 2009; Osborne 2009; Orr et al. 2012) have documented the severe impacts these dams would have on fisheries yield and food security, primarily because the dams act as a barrier to fish migration, which in turn affects breeding and recruitment. Substantial fish mortality is also predicted to result from downstream passage through turbines (Halls and Kshatriya 2009). Other ecological changes include those common to large dams elsewhere, such as sediment trapping, altered flow regimes, lowered water temperature downstream of dam outlets, and creation of still water environments upstream of dam walls.

In addition to the multiple benefits of increased electricity supply, the proposed dams may improve river navigation and enhance irrigated agriculture due to increased dry-season flows (ICEM 2010).

Public debate about the dams has been widespread and is ongoing. Opposition is mainly centered on impacts on fisheries and associated livelihoods, and the forced displacement of riparian communities (e.g., Save the Mekong Coalition, www.savethemekong.org.). Proponents in Laos argue the need for electricity and income to lift the country out of the Least Developed Countries category, and that harmful effects of the dams can be mitigated (see, for instance, Department of Energy, www.poweringprogress.org).

The fisheries case has been recognized by government management agencies in Laos, albeit reluctantly and belatedly. In 2009, a senior administrator concluded a technical meeting on dams and fisheries by saying "Forget the fish; if we worry about the fish, we will never have dams" (author's personal observation). The approach has evolved since then in response to the sustained public discourse (e.g., Save the Mekong Coalition, www.savethemekong.org.) and MRC and other technical reports (e.g., Halls and Kshatriya 2009; ICEM 2010; Orr et al. 2012) on the negative impact of the dams on fisheries resources and fisher livelihoods. In the case of Xayaburi Dam, which will have a dam wall 32 m high and span the entire river, fish passage (ladders and lifts) is proposed as a means of ensuring upstream migration of fish, deflectors and fish-friendly turbines to facilitate downstream passage, in conjunction with stocking of hatchery-reared fish. The fishway consulting company for the Xayaburi Dam considers that, in its experience, "there is always a solution to a fish passage problem" (Fishtek Consulting, www.fishtek.co.uk), but this seems contrary to decades of experience and billions of dollars in research and development elsewhere that indicate that lasting ecosystem-wide impacts of high dams cannot be compensated for through fish passage and hatchery technology (e.g., Agostinho et al. 2008; Williams 2008; Ferguson et al. 2011; Brown et al. 2013).

The Don Sahong Dam is located on one channel of the 11-km-wide Khone Falls in southern Laos. The channel is the Hou Sahong, which is the major upstream route used by migrating fish (Roberts and Baird 1995). Proposed mitigation involves engineering works to remove rocks, lessen gradients, and widen the channels on each side of the Hou Sahong, with the overall intention of making the channels more accessible and functional for migrating fish. The efficacy of the strategy can only be assessed postconstruction.

Assessment of the impacts of the mainstream dams has, until recently, been largely isolated from consideration of the full array of dams being planned for both the mainstream and tributaries. Ziv et al. (2012) have modeled impacts of various combinations of mainstream and tributary dams planned for construction before 2030 and have shown likely reductions in migratory fish biomass of up to 51% and up to 100 fish species becoming critically endangered. Kondolf et al. (2014) analyzed the effects of different scenarios of current and planned dams on sediment transport. Under a definite future scenario of 38 dams built or under construction, cumulative sediment reduction to the Mekong delta would be 51%. After construction of all planned dams, cumulative sediment trapping would be 96%. The impact would be severe, not only on freshwater fisheries and agricultural productivity, but also on the marine fishery dependent on the outflow of the Mekong River and on the integrity of the delta landform. These two reports testify to the importance of integrated planning and assessment of cumulative impacts before committing to large-scale developments.

Lessons Learned—Governance, Hydropower, and Fisheries in the Mekong

Six lessons can be drawn from the experience to date with development of dams on the mainstream in the lower Mekong basin. A broader analysis of integrated management experiences in the Mekong River and Murray–Darling River in Australia (Campbell et al. 2013) identified additional lessons, several of which complement those below.

Lesson 1: decisions about resource use can be unrelated to resource management

Decisions about mega-infrastructure such as dams are often made at the highest levels of government, beyond the level of managers of energy or natural resource agencies and the planning processes they administer. For instance, the proposed Sambor Dam in Cambodia, to be built by a Chinese developer, appears to be just one element of a centrally organized Chinese strategy for investment and political influence in Cambodia (China's Cambodian hegemony 2009). The Don Sahong proposal in southern Laos was signed off by the provincial governor long before any consideration was given to its contribution to the national power grid or its impact on the fishery, the tourism amenity of the Khone Falls, or the highly endangered Mekong dolphin population inhabiting the pool below the dam site.

Lesson 2: different public viewpoints and value judgments by political leaders must be acknowledged

We are not all on the same page. Different commentators will variously favor different perspectives, such as immediate economic development, electricity supply, overt signs of development (physical infrastructure), and income to government on the one hand; or livelihoods, community cohesion, long-term food security, ecosystem functioning, and maintaining biodiversity on the other. Balancing these different perspectives should be on the basis of scenario testing backed by good science. However, decisions at national and regional levels are always value judgments made by political leaders.

Lesson 3: integrated planning is essential for rational development of natural resources

The Mekong and its tributaries in Laos provide numerous sites for hydropower dams. The Ministry of Energy and Mines lists 17 dams already operational, 13 under construction, and 20 in various stages of planning (Department of Energy Business, www.poweringprogress.org). These dams have been planned on the basis of site suitability and electricity generation potential, with evaluation of environmental impacts happening only after the decision to proceed with the dam. Obviously a better approach would be to consider hydropower requirements concurrently with potential environmental and social impacts, as well as biodiversity considerations. Actually, such a strategic environmental assessment of the lower Mekong mainstream dams was commissioned by the MRC in 2009–2010. Two of the recommendations from the report were that decisions on mainstream dams should be deferred for 10 years and that mainstream dams should never be used as a test case for proving dam hydropower technologies (ICEM 2010). These recommendations have not been implemented.

Lesson 4: decentralization of government hinders sustainable management of natural resources

Decentralization of government functions may be beneficial for local delivery of services such as health care, policing, roads, and other infrastructure. But decentralization is counterproductive for cohesive, integrated management of the national estate. This is especially the case whereby benefits of development accrue locally but the environmental and social impacts are shared widely or even transferred elsewhere. In the case of mainstream dams in Laos, several of the concessions were granted by provincial authorities, justifiably keen to bring development to their provinces but unaware of, or unconcerned about, the national and regional implications of damming a transboundary river. One senior member of the national government, in reflecting on this situation in 2008, lamented, “We have lost control of planning” (author’s personal observation).

Lesson 5: technical information is essential for decision making and assessment of trade-offs

Objective, rigorously derived technical information is essential to support discussion and decision making on issues that, of necessity, involve trade-offs. The fact that fisheries have received some consideration in planning the dams on the Mekong has not been a consequence of the easily perceived size of the fishery. Rather, it is due to promotion of fisheries considerations by the MRCS, backed by high-quality scientific reports that have provided quantified evidence on the role of fish migration in the lower Mekong (e.g., Roberts and Baird 1995; Poulsen et al. 2002; Baran et al. 2005), the regional importance of fisheries for food security and livelihoods (Hortle 2007; Orr et al. 2012), and the impact of mainstream dams on life cycles of numerous fish species and fisheries productivity (Baran and Myschowoda 2009; Halls and Kshatriya 2009). While these reports may have stimulated the developers’ design modifications for fish passage at the Xayaburi and Don Sahong dams, the information has not influenced the Laos government’s overall planning for the number and location of mainstream dams.

Lesson 6: difficulties in comparing formal and informal economies, or monetary and nonmonetary values, hinder policy development

Dams are part of the formal economy. Engineers and accountants can estimate costs of construction, the amount of electricity generated, and the annual returns to developers and governments from the sale of the electricity. The estimated income from large hydropower dams is huge and is obviously attractive for governments wishing to advance the economic development of their countries and to secure energy supplies (see ICEM 2010). Fisheries in the Mekong are mostly part of the informal economy. A portion of the catch is not traded but is consumed by the fishers or bartered for other goods. Fisheries are not formally taxed, so they do not contribute directly to government income. Further, their importance in terms of food security, health, and welfare lies largely with disenfranchised people with little ability to influence national debate.

The comparison of the relative benefits of dams and fisheries is obviously fraught. The discussion would be greatly enhanced if monetary values could be assigned to the informal economy of the Mekong fisheries and to other nonmonetary benefits, such as maintaining biodiversity, preservation of endangered species, and the cultural and societal value of a free-flowing river.

A Better Future Forfeited

The World Commission on Dams (WCD 2000) outlined seven strategic priorities for hydropower planning, development, and management based on the recognition of human rights, the right to development, and the right to a healthy environment. In brief, these are gaining public acceptance; comprehensive options assessment; addressing existing dams; sustaining rivers and livelihoods; recognizing entitlements and sharing benefits; ensuring compliance; and sharing (transboundary) rivers for peace, development and security. Elements of these approaches have been partially and occasionally considered in Laos, most prominently at Nam Theun 2 Dam (Cruz-del Rosario 2011), although the outcomes have been highly contested (Lawrence 2009; Baird et al. 2015). However, comprehensive options assessment, or integrated planning, has never been rigorously undertaken at the national level. This is unfortunate as the country is traversed by a large mainstream river with many tributaries arising in mountains, providing numerous sites for dams.

Integrated, consultative planning could have provided for large-scale hydropower development and resultant diverse, nation-changing economic and development benefits, as well as maintenance of community aspirations, the conservation of important biomes, wild rivers and fisheries, and a free-flowing transboundary river. In this regard, Laos has lost the opportunity to be a world leader in best-practice hydropower development. Nevertheless, economic gains will be realized, and with continued advocacy for benefit-sharing and compliance, those gains may partly extend to the communities affected. On the debit side, the fishery and other ecosystem services provided by the river will be permanently degraded.

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How to Transmit Information and Maintain Knowledge in the Context of Global Change for French Inland Commercial Fishers

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Abstract.—For the past decade, French inland commercial fishers have faced increasing difficulties in maintaining their fishing and marketing activities for the fish consumption sector. Lack of political will, combined with short-sighted political decision making and increasing regulatory constraints, has made it difficult to develop opportunities for inland commercial fishing. A lack of collective organization among inland fisheries markets, the sector's poor visibility and image, and conflicts with recreational angling associations have also contributed to these difficulties. Consequently, some small-scale commercial inland fisheries are undergoing liquidation. However, this sector has also made important contributions to society by diversifying its activities through environmental services such as data collection for knowledge and conservation of native fish biodiversity. Indeed, in most cases, professional inland fishers provide the only data on fish stocks and the health of continental aquatic ecosystems. Indeed, this information, knowledge, and associated heritage are part of a cultural legacy that deserves to be preserved, given that fishing plays an important role in the social and cultural identity of many fluvial and lakeside territories. Commercial fishers could also play a significant role in implementing long-term cross-sectoral policies through their contributions to sustainable hydrosystem management, local gastronomy, and ecotourism. This paper presents the strategy that was used to try to halt the general decline of small-scale commercial inland fisheries in France and Europe and describes why the strategy failed.

Introduction

This paper explores the current situation of commercial inland fisheries in France and describes the unsuccessful efforts of the entire profession to curb the rapid decline of its small-scale businesses, from more than 4,000 fishers in the mid-1970s (Luneau et al. 2003) to only 400 fishers in early 2015. This decline is occurring in other European countries as well, most of which are facing the same issues as France as a direct result of social transformations that have taken place during this period. Traditionally, commercial fishing has served as

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a complementary activity for small farmers, either for sale or their own consumption.

The collapse of this workforce resulted in a sharp reduction in fishing activity, which then transitioned into a separate activity with strong regulatory constraints that limited the establishment of new businesses. Using eel fisheries as an example, this paper challenges the existing fisheries governance and explains why changes must be made to save inland commercial fisheries from extinction.

Strengths and Weaknesses

Professional inland fishers are a minority in Europe, and only Finland and France have national professional associations. In other European countries, professional inland fishers are represented either by professional associations that include both sea and inland fishers or by inland associations for both professional and recreational fishers. This lack of specific representation weakens the ability of inland commercial fisheries to influence decision making (Ernst and Young 2011). This is particularly true in France where conflicts between recreational fishers and commercial fishers over fishery resources and fishing areas have emerged (authors' personal observation).

All inland fisheries share some strengths stemming from the traditional nature of their activities. Commercial fishers are the guardians of specific expertise and have developed empirical knowledge about aquatic ecosystems. Moreover, this knowledge is the legacy of the transmission of knowledge and savoir-faire from older fishers to new entrants into the profession (Boisneau and Mennesson-Boisneau 2001; Ernst and Young 2011). Because of their daily presence on lakes and rivers, they are keen observers and sentinels of aquatic habitats. They are often the ones who quickly alert authorities when there are problems with fish stocks or ecosystems, unlike government departments that have been less committed to commercial fishers and anglers since the creation of the French National Agency for Water and Aquatic Environments (ONEMA) in 2006 (Thomas Changeux, Institut de Recherche pour le Développement, personal communication).

Commercial inland fisheries face several major threats (Allan et al. 2005; Dudgeon et al. 2006, cited by Suuronen and Bartley 2014; CNPMEM et al. 2009; FAO 2010, 2012; Ernst and Young 2011):

- The collapse of fish stocks (mostly for diadromous species such as European Eel *Anguilla anguilla* L. and Alantic Salmon *Salmo salar* L.) and subsequent restrictions on fishing activities;
- Water and fish contamination (e.g., polychlorinated biphenyls (PCBs, heavy met als, and phytosanitary products) and subsequent bans on the sale of fish;
- Rapid changes in ecosystems and fish populations following the introduction of invasive species in a context of climate change (Bates et al. 2008; Barange and Perry 2009; both cited by Suuronen and Bartley 2014);
- Lack of consistent strategies for fisheries management and product marketing;
- Lack of fishers' organizations or, where they do exist, lack of support from authorities;
- Limited recognition of these organizations as advocates for aquatic ecosystems and resource conservation, mainly because of overlapping responsibilities among decision-making bodies at different levels (e.g., local, basin, national, and European Union [EU]);
- Limited ability to counter the influence of agroindustrial lobbies and little support from environmental nongovernment organizations that criticize commercial fishing without fully understanding it; and
- In Eastern countries, a drastic decline in inland fisheries and imbalance between recreational and commercial fishing after the collapse of centrally planned economies and the shift to private systems.

The number of commercial fisheries that depend on migratory species is expected to keep decreasing in the short to medium term. Other fisheries could survive, but commercial fishing opportunities are generally restricted because of a lack of political will all across Europe (Ernst and Young 2011).

Moreover, commercial fishers on the Loire River have contributed to modeling of eel migration to the ocean by providing catch data and explanatory variables over a period of 20 years (Acou et al. 2009; P. Boisneau, C. Boisneau, A. Acou, and E. Feunteun, paper presented at the American Fisheries Society 144th Annual Meeting, 2014). Loire River fishers also participated in EELIAD (European Eels in the Atlantic: Assessment of Their Decline), an EU-funded collaborative program investigating the marine migration of the European Eels, and made it possible to collect the first data about the downstream migratory behavior of the silver eel and to assess the most important factors influencing its production and migration success (Aarestrup et al. 2009). Such fruitful collaborations are unfortunately all too rare. Professional fishers still have progress to make, but so do research organizations, fishery management agencies, and decision makers. These groups need to make better use of fishers as key resource management partners and establish funding mechanisms for sustaining small-scale fisheries (E. Amilhat and coauthors, paper presented at the 16th Japanese-French Oceanography Symposium, 2015).

Indeed, on the Loire River, as paradoxical as it may seem, maintaining commercial fisheries is essential for the sustainable management of one of the last wild rivers in Europe and the fish species it contains. The glass eel restocking programs, which result from the requirements designated in an EU eel regulation adopted in 2007, are mainly implemented by commercial fishers. The objective of this regulation is to support preexisting stocks and increase silver eel escapement to the sea, transferring glass eels caught in estuaries to sites with conditions deemed favorable to their growth (e.g., optimal habitat and water quality, high productivity, and low density) and survival (e.g., reduced mortality). In France, professional fishers are involved at the local, regional, and national levels, with the technical and financial coordination and implementation of activities between different watersheds, including glass eel collection to enhance growth, transport, and release eel fingerlings in receiving catchments (authors' personal observation).

Financial and Regulatory Obstacles

Severe limitations on eel fisheries have accelerated the decline of professional inland fishing. These limitations include the adoption of a quota system under EU eel regulation to gradually decrease glass eel fishing capacity and restrict fishing periods, as well as the banning of fishery products marketing under a PCBs action plan. Moreover, government incentives have encouraged fishers to leave the profession (Figure 1), and the disappearance of the Asian market, which was a major consumer of French glass eels, has negatively affected the market demand. Indeed, the drastic reduction in landing prices after 2007 has had profound and lasting effects, particularly in France as France is the leading European producer of glass eels for consumption (Figure 2). With no financial compensation mechanisms, about half of French inland commercial fisheries, which directly depend on this fish resource, disappeared.

The drop in prices has also affected stocking programs, which appear to be economically unsustainable because European demand does not actually correspond to initial commitments made by EU member states that use this management measure, thus influencing the decline in price. In France, marine and inland professional fishing organizations are taking the lead in the national eel restocking program to allow France to reach its objectives. However, since 2014, inland fishing organizations have been forced to find private funding for at least 20% of the cost of these programs (and up to 50% depending on the activity) because of a change in European Commission funding rules for entities that are not recognized as "bodies governed by public law" (Journal Officiel de l'Union Européenne 2014).

In spite of a relatively high co-funding rate and generally much better access to co-funding in France, as compared to other EU member states, this new rule put an end to the already infrequent projects led by stakeholders other than commercial fishing organizations, as well

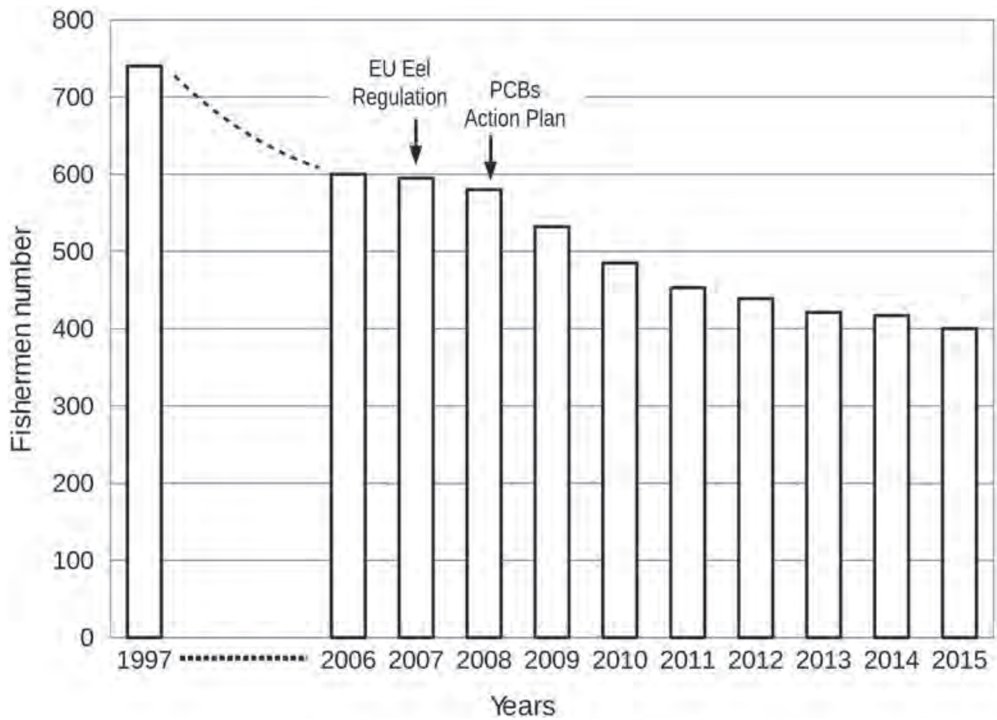

Figure 1.—Change in the number of professional inland fishermen in France since 1997. (Source: CONAPPED, unpublished data).

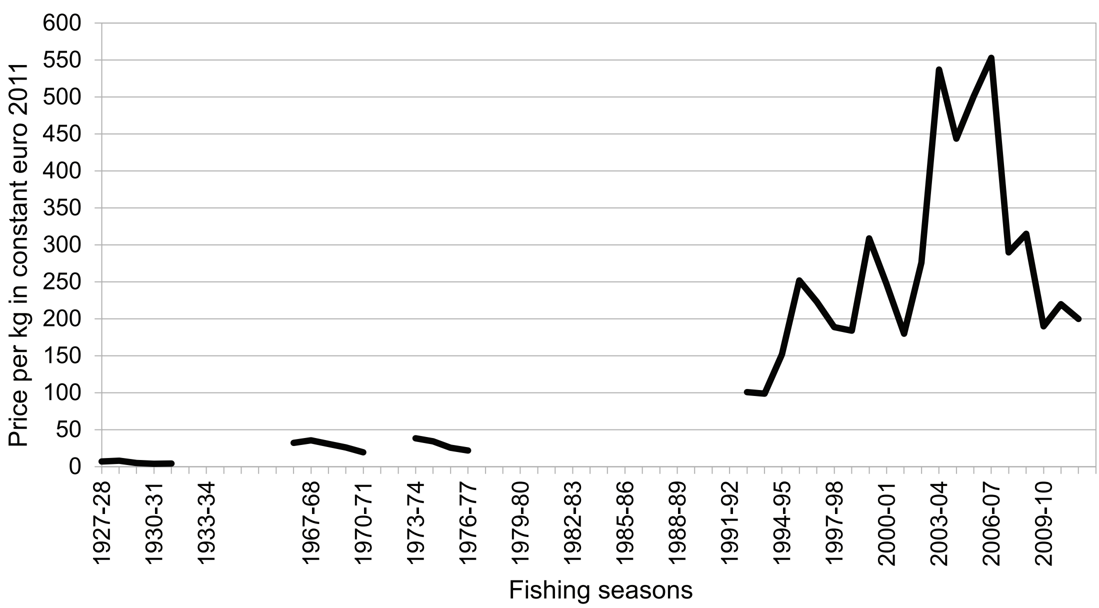

Figure 2.—Variation of the price per kilogram of glass eel (landing prices) during the 20th century and the beginning of the 21st century (inland and marine fisheries). (Source: E. Amilhat and coauthors, paper presented at the 16th Japanese-French Oceanography Symposium, 2015).

as limiting awareness-raising among other potential project leaders: while the EU requires member states to conduct restocking operations, those planned for the winter of 2014–2015 were interrupted, and the submission of new projects for the 2015–2016 season was prevented. To offset the loss of these stocking projects, the French Ministry of Ecology was forced to relaunch a call for proposals because the goals set by the European Union were not achieved in some river basins (Ministère de l'Écologie, du Développement Durable et de l'Énergie 2015a). The same EU rule now applies to scientific monitoring (Journal Officiel de l'Union Européenne 2014). Furthermore, the borrowing costs for these European stocking or scientific monitoring programs are now no longer eligible for national co-funding: the interest on bank loans taken out to cover advance payments will no longer be reimbursed (authors' personal observation).

In this context, the French professional organizations must take economic risks to fulfill these government-supervised obligations without being given the means to comply with the obligations under satisfactory conditions. This situation is particularly inequitable given that restocking projects are temporary mitigation measures to offset eel mortality factors other than fishing (e.g., intensive farms, heavy industries) for which other stakeholders are responsible. Unfortunately, these same stakeholders refuse to recognize their contribution to the problem and to pay their share. More generally, professional fishers face strong obstacles to receiving technical and financial support for their contribution to scientific programs (through catches in aquatic habitats that require specific knowledge and know-how, such as for European Eel) and other general interest services. Insufficient returns on investment with very long payment terms further weaken the profession. In France, the number of professional fishers (all target species included) had declined to 400 fishers in 2015. At this time, inland fishers organized into the National Committee for Professional Freshwater Fishing (CONAPPED) and reminded the European Commission of the seriousness of the situation both for the profession itself and for inland fishery resources management, in the context of the Common Fisheries Policy reform.

An Unsuccessful Strategy at the International Level

For about 25 years, French professional fishermen have been warning authorities about the gradual degradation of aquatic ecosystems. In the early 2000s, they asked European authorities to establish a restoration plan for the European Eel on a scale that has been never implemented. They also agreed to the inclusion of this species in Appendix II of CITES (Convention on International Trade in Endangered Species of Wild Fauna and Flora), which ensures strict traceability of commercial movements within and outside Europe. Professional fishers agreed to these efforts not only to ensure sound management of endangered fish species (such as European Eel, Atlantic Salmon, or Allis Shad [also known as Allice Shad] *Alosa alosa* L.) and their essential habitats, but also to conserve age-old fishing practices that are an integral part of the economy and culture in the European river basins where these species live. This activism has received little attention from the European Inland Fisheries Aquaculture Advisory Commission (EIFAAC) of the Food and Agriculture Organization of the United Nations (FAO), aside from minor advances. But professional fishers cannot participate in these meetings anymore since 2004 because of huge political and administrative obstacles. Thus, their knowledge and expertise are not taken into account.

As far as the International Council for the Exploration of the Sea (ICES) is concerned, it recommends reducing all anthropogenic causes of fish mortality as much as possible. But, in fact, only mortality due to fishing is used as an adjustment variable in models, even if the scientists are unanimous in their agreement that fishing is not the only factor; the "as much as possible" is linked only to fishery management while economic and social aspects are not taken into account. Such a vision stems from the obstinacy of the EU, which makes decisions based advice from the ICES and wants to find an administrative solution to the resource decline at all costs, even if that response is insufficient. It does not take into account the economic and social benefits of the fishing profession and the fact that restoration will not be successful because other mortality factors are not addressed (authors' personal observation).

Faced with these obstacles from European authorities, and after years of successive French governments refusing to arbitrate between the various freshwater stakeholders, the National Committee for Professional Freshwater Fishing, in partnership with other organizations in Europe (notably in Sweden, Finland, and the Netherlands), developed a strategy in 2013 based on two approaches:

- A nonmonetary approach to create an inland fisheries advisory council (similar to one that exists for maritime issues and for aquaculture) to bring political visibility to professional inland fishing. The creation of a forum for dialogue to strengthen the professional sector was viewed as a mechanism to enhance the position of commercial fishers and their ability to influence decisions concerning their future.
- A monetary approach, within the framework of the new European Maritime and Fisheries Fund, particularly focused on financial support for environmental services provided by inland fishers (including their collaboration with scientific programs) and the development of new commercial activities. An example is the establishment of economic outlets for species that have not increased in value (or not enough). This is particularly relevant for some invasive species as French professional fishers face strong political and legal obstacles in finding innovative ways of removing the undesirable species or in creating added value through industrial processing.

Unfortunately, these two strategies were unsuccessful. Despite support from the European Parliament's Committee on Fisheries, the advisory council proposal was rejected by the European Parliament. Almost all of the proposed amendments to the new European Maritime and Fisheries Fund were denied.

In the end, apart from a few marginal steps, the professional freshwater fishing situation in Europe has not changed with the Common Fisheries Policy reform and the implementation of the new fund. The authorities only supported certain investment operations or sought to mitigate the loss of fisheries through plans for temporary or permanent cessation of activity. The only current possibilities (mainly for European Eel) remain certification and joint financing for restocking, in spite of recent difficulties in terms of co-funding rates. Nevertheless, payments for environmental services are increasingly used in environmental and development policies, particularly in southern countries (Bureau 2010). Surprisingly, Europe still does not make much use of payments for environmental services, with the exception of the Common Agricultural Policy agri-environmental measures introduced in the 1990s, which have evolved towards compensation for services rendered (Aznar 2013). As far as certification is concerned, the fishing profession has begun to join forces with the Sustainable Eel Group, a European science and conservation nonprofit organization that brings together organizations and individuals involved in eel recovery.

The Profession's Adaptive Capacity Has Reached Its Limits

There is no reason that approaches previously used in agriculture cannot be applied to fisheries, especially inland fisheries. Although they are under a great deal of pressure from a number of different directions, commercial inland fishers have adapted to take environmental issues into account. In France, fishers have developed considerable environmental understanding and protection skills, though authorities unfortunately do not recognize the value they provide to other stakeholders and could provide to aquatic habitat restoration. This expertise includes

- Fish rescue operations prior to draining of waterways, canals, stormwater retention basins, and so forth.

- Support for fish management diagnostics in ponds and balancing of fish populations in natural aquatic habitats by regulating overdense or exotic species such as Black Bullhead *Ameiurus melas* Rafinesque, Pumpkinseed *Lepomis gibbosus* L., exotic carps of the Cyprinidae family, Wels Catfish *Silurus glanis* L., spinycheek crayfish *Orconectes limosus* Rafinesque, signal crayfish *Pacifastacus leniusculus* Dana, and red swamp crayfish *Procambarus clarkii* Girard.
- Sampling catches for research purposes, to study fish population structures, monitor diadromous fish migrations, perform health studies, and so forth.

However, professional fishers cannot easily diversify their activities, even though it would allow them to maintain their skills and potentially pass them on to a new generation of fishers, in France or elsewhere in Europe where they may have already disappeared. Indeed, they face many political or legal obstacles, including inconsistent public policies, such as the authorities' inability to enforce the French Environmental Code and prevent the transfer of nonnative species between watersheds, which is tolerated in the case of Wels Catfish (Copp et al. 2009) but prohibited in the case of invasive American crayfishes (Basilico et al. 2013).

In general, most professional freshwater fishers are fully aware of their responsibilities in the conservation of fishery resources and suffer the consequences of sector-based policies that do not respect the management principles of an ecosystem approach, as defined in a United Nations workshop in Malawi in 1998 and adopted at the Fifth Meeting of the Conference of Parties to the Convention on Biological Diversity in 2000. These policies hold the fishing profession mainly responsible for the erosion of continental fish stocks while ignoring the responsibilities of multiple stakeholders involved in the degradation of aquatic ecosystems. In spite of the European Water Framework Directive mandate that all EU water bodies must attain "good ecological status" by 2015 under criteria defined in Annex V of this directive, 47% currently have "bad ecological status" under these criteria, meaning that human activities have had strong impacts on the ecological characteristics of aquatic plants and animal communities (European Commission 2012). Indeed, the balance of power that governed the implementation of this directive resulted in a policy favoring qualitative water management, excluding key parameters for ichytofauna (e.g., endocrine disruptors) at the expense of quantitative management, which is in fact fundamental, as with the example of the impact of irrigated agriculture on spawning grounds (Elola Calderón 2010). In addition, certain biological indicators such as diadromous fish have also been excluded (authors' personal observation).

Strengthening obsolete restrictions from an era when fishers were far more numerous will not bring about solutions to the problem of fish stock decline and help protect aquatic ecosystems. There is also a need to shift away from an approach in which policymakers base their decisions almost exclusively on recommendations from scientific experts. In many cases, regular, reliable, and controlled data can only be provided by commercial fishers, especially in the case of European Eel in waters deeper than 1.5 m because electrofishing is not feasible in France due to regulations and technical limits. While other stakeholders do not comply with or enforce compliance with regulatory obligations to report catch data, the fishing profession would prefer a more participatory approach that sees fishers as much more than a source of data that is later used against them. Indeed, the majority of scientific models, which are solely based on catch data provided by professional fishers, automatically assume that the natural mortality rate is constant and truly natural.

This is evidently not the case for migratory fish species, as there has been clear ecosystem damage in the past 50–60 years (Adam et al. 2008). In this context, the more fishers report to fishery management agencies, the more trouble they make for themselves because the real causes of eel decline are not taken into account with the same importance, as it depends on the stakeholders involved (CONAPPED

2010). Out of 88,000 obstacles to fish migration in France, 1,555 are in priority eel conservation areas and must be adapted to ensure free passage of eels, but only 477 structures were made passable by the end of 2015 (ONEMA, in press). Given this situation and all the other anthropogenic pressures on this species, some scientists consider it impossible to estimate anthropogenic mortality separate from fishing with currently available information (Ministère de l'Écologie, du Développement Durable et de l'Énergie 2015b).

The underlying objective of commercial inland fishers is the preservation of biodiversity, which is necessary for sustainable management for the common good and which will ensure long-term maintenance of the economic resources. Fishers must no longer be treated wrongfully as a destructive force that erodes biodiversity (CNPMEM et al. 2009; Bernard et al. 2014). For this change to happen, prejudice against professional fishers must end, and awareness must be raised among scientists and policy decision makers. This will not be possible without the support of civil society, which must mobilize around fishers as it already has for other minorities. How will this change take place? Perhaps it will change through information campaigns on social media showing examples of the potential cascading effects of commercial fisheries extinction. The example of the Volga River in Russia is instructive because commercial fisheries were blamed for the fish stock decline and thus outlawed. This resulted in an explosion in poaching and further degradation of these stocks (D. F. Pavlov and Y. V. Gerasimov, presentation at the Global Conference on Inland Fisheries, 2015). France could soon face a similar situation for several species such as European Eel (glass eel stage), the migratory Salmonidae in coastal areas (Brown Trout [also known as Sea Trout] *Salmo trutta trutta* L. and Atlantic Salmon), Northern Pike *Esox lucius* L., or Walleye (also known as Pikeperch) *Sander lucioperca* L. (authors' personal observation).

But as long as European authorities ignore the environmental contribution of professional inland fishers and France remains neutral and implicitly supports the most powerful stakeholders, it will be difficult to create social change. However, it is up to the community rather than government authorities to define how the common good is shared.

The United Nations Context to Support Small-Scale Fisheries

In 2014, the FAO's Committee on Fisheries formally endorsed the International Voluntary Guidelines on Securing Sustainable Small-Scale Fisheries in the Context of Food Security and Poverty Eradication (FAO 2015). These guidelines will now have to be implemented. In this context, they should be relevant for all vulnerable and marginalized groups that depend on small-scale fisheries. This is the case for European professional inland fisheries.

As the International Collective in Support of Fish Workers recently outlined, representatives of fish worker organizations from developed countries pointed out that while the small-scale fisheries guidelines focus on the south, there are marginalized and vulnerable groups in the north as well. An exclusive focus on the south would give industrialized countries an excuse not to implement these guidelines (ICSF 2014).

During the United Nations Conference of the Parties to the Convention on Biological Diversity, held in Nagoya, Japan in October 2010, a coordinated ecosystem approach was presented and promoted as a necessary cross-functional conceptual approach. This ecosystem approach to fisheries (EAF) was evoked in the FAO's international guidelines on securing sustainable small-scale fisheries (FAO 2015). But in 2016, how is EAF applied to European aquatic habitat restoration and fishery resource management?

Conclusion

The commercial fishing situation in France has now reached a critical stage. Some professional fishers associations, like those on the Loire River, provide the only data the government uses to assess fish stocks and to estimate the effectiveness of public restoration policies. Professional fishers in France and elsewhere in Europe made a deliberate choice to contribute their skills to the protection and restoration of fish fauna biodiversity. But fishing restrictions for certain species, as well as chronic obstacles in accessing funding mechanisms to diversify their activities (e.g., environmental services that are already provided at the European level for agriculture), are gradually leading European professional inland fisheries and their cultural heritage towards increasing economic insecurity, closure, or accelerated decline (Ernst and Young 2011).

What price will society pay in terms of aquatic habitat degradation? How can the gap be reduced between the ecosystem approach theory and its application? Lessons from the past show that it is not the lack of ecological data, but rather the lack of good governance that presents the biggest obstacle to EAF implementation (Suuronen and Bartley 2014).

In this context, how can inland commercial fisheries become involved in such an approach before it is too late? The causes of the decline of European fish stocks are multiple and extend well beyond fishing: the depletion of wetlands, habitat degradation through the construction of obstacles to fish migration, environmental contamination and pollution, turbines, diseases, parasitism, and nonnative and invasive species. The sum of these disturbances has resulted in substantial deterioration in the quality of essential habitats for fish species (Adam et al. 2008).

While professional fishers have kept their promises and collected information, and planned studies, the inconsistency in water public policy outcomes, as well as increasingly restrictive administrative procedures, will gradually drive them into bankruptcy if nothing is done to reverse the situation. First, fishers in the Seine, Rhone, Garonne, and Loire River basins will become bankrupt, followed by those in other places in France and across Europe.

Ireland prohibited eel fishing in 2009 and now has difficulty assessing the effectiveness of eel conservation measures that were implemented. In 2015, an ongoing scientific study involving former eel fishers and the reauthorization of commercial fishing activities are seriously being considered (Fishermen knowledge needed for scientific eel study, 2015). What can be done to prevent this type of situation across Europe?

This example also shows the need to promote a broader ecosystem approach to better understand the vulnerability of human communities to global change (i.e. large-scale changes in Earth's system and society). How will inland fishing communities adapt to these transformations? Is there a strong risk that their disappearance will accelerate the anthropization of these very biodiverse hydrosystems, which are already highly degraded? (Bernard et al. 2014).

This raises the question about whether the role and governance of inland commercial fisheries in Europe should be adjusted, and if so, in what way? Even if commercial fishers are represented in consultation structures such as water or fishery management commissions, as it is often the case in France, their points of view are marginalized because their political weight is insufficient. Only participatory science and an extension of governance to citizens, as well as drastic changes in the managerial behavior of the EU and national fishery authorities, could cause positive change. The authors of this paper endorse the following principles taken from the DIMPAT program (Bernard et al. 2014):

- The critical importance of small-scale fisheries has to be taken into account in public policies for rural development.
- The sustainability of fishery production chains in coastal, estuarine, and inland habitats must also be associated with a reduced ecological footprint for other uses.
- Participatory research programs have to be initiated and strengthened as soon as possible to assess the evolution of aquatic habitats under pressure from global change.
- The diversity of small-scale fisheries is a tremendous resource. Protecting these fisheries must be a stated priority for the foundation of ecologically sustainable development supported by public aid. It should also be a strong focus area for regional planning.

- The diversity of fish production through out the seasons protects food security and promotes French culinary culture. These niche productions need to be protected and assisted in their ability to innovate.

Fishery management agencies can no longer ignore the traditional knowledge of professional fishers and consult only scientists that make limited contributions to fishery management. That is what Elinor Ostrom, the Nobel Prize recipient for economics in 2009, demonstrated through her work on social-ecological systems. The social aspect is essential because it refers to the position and involvement of each stakeholder in the better use of goods and services provided by ecosystems (Bernard et al. 2014).

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Fisheries Governance in the 21st Century: Barriers and Opportunities in South American Large Rivers

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Abstract.—South American large-river fisheries are experiencing a growing pressure due to mining activity, construction of dams, water diversion, dredging, commercial overfishing, pollution, floodplain deterioration, agriculture, and development. Despite the fact that artisanal fisheries represent a valuable resource for many riverine communities and play a critical role in assuring food security and poverty alleviation, managers are challenged to develop sound governance processes that ensure the sustainability of resources and fishing communities. The lack of effective governance processes in artisanal fluvial fisheries is rooted in several social, economic, institutional, and ecological/environmental constraints. Most large-river fisheries are managed under a conventional approach, applying centralized government control policies that minimize stakeholders' participation in management decision making. River-fisheries governance is dependent on institutions, policies, and economic and political scenarios that are outside the fishery sector. Market demands and construction of dams and river fragmentation, mining, pollution, cattle agriculture, deforestation, and recreational fishing pressure are all factors that have the potential to alter fisheries sustainability. Governance mechanisms in South American large rivers can be developed at three levels but need to prioritize economic growth, food security, employment, equitable access to resources, and poverty alleviation and promote and integrate the sustainable use of fluvial resources through stakeholders´ involvement in decision-making processes. To achieve such goals, new institutional and legal arrangements should be promoted envisioning small-scale fisheries as ecosystem services and implementing an ecosystem-based approach that integrates ecological and human components to support better governance processes.

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Introduction

Management of South American large-river fisheries is challenging for managers due to increasing fishing pressure, construction and operation of dams, water diversion, dredging, pollution, floodplain deterioration, and agricultural and cattle development (Barletta et al. 2010). River fisheries play a critical role in the livelihoods of artisanal fishing communities by providing food security, nutrition, employment, and poverty alleviation (Berkes et al. 2001; Béné et al. 2007). The number of people employed in the inland fishery sector has increased during the past 50–60 years (Welcomme 2011). In the Amazon basin, for instance, around 100,000 fishers produce gross revenues of about US$200 million (Almeida et al. 2001, 2003), contributing 33% of the local economy (Almeida et al. 2004). However, despite the importance of river fisheries in South America (Carolsfeld et al. 2003; Barletta et al. 2016), conflicts and related resolving mechanisms have not received proper attention.

Basic governance theory and practice have grown and received increasing attention during the past decades (Gray 2005; Kooiman et al. 2005, 2008; Bavinck et al. 2013), but these have been barely applied to South American river fisheries. Although fishery agreements and comanagement initiatives have been successfully implemented in several areas of the Amazon basin (Almeida et al. 2000, 2001), governance and its application to address fishers´ demands and interests and fish conservation still remain poorly developed for most of South American large rivers.

This study reviews some of the main issues faced by artisanal fisheries in South American large rivers, highlighting those factors that hinder the ability to enable more effective governance processes and also discussing the needs and opportunities for governance improvements.

Main Factors Affecting Fisheries Governance in South American Fluvial Systems

Large-river fisheries of South America are all small-scale and considered multifaceted socio-ecological systems (Berkes et al. 2001). They involve diverse full- and part-time fishers, middlemen, transporters, local markets and processors, retailers, and management agencies. All these sectors are connected through variable spatial and temporal relationships that are modified according to fishing trends regulated in turn by the hydrological regime. South American fisheries are almost all based on open-access management policies and mostly supported by lateral and long-distance migratory species.

The Amazon basin is by far South America's most developed fishery in terms of harvest and target-species diversity (Ruffino 2004; Barletta et al. 2016). These fisheries provide well-being and mobilize local market economies, representing a valuable resource for many riverine communities (Bartley et al. 2016) and also for rural people inhabiting surrounding forest landscapes (Coomes et al. 2010). Riverine fishers often use economic strategies that combine fishing with farming and cattle ranching, particularly in those large rivers with alternating dry and wet phases.

River fisheries governance depends on institutions, policies, economic and political scenarios, and patterns of decision making that often are outside the fishery sector (Jentoft 2007; Mahon et al. 2008). Such problems exhibit the difficulties to put in practice effective governance process at local, regional, and basin scales. Lack of effective governance processes in artisanal fluvial fisheries is rooted in several barriers such as deficient or null statistical information, fisheries managed and enforced only at stock levels, and lack of policy responses despite signs of overfishing in several basins (Bayley and Petrere 1989; Tello and Bayley 2001; Agostinho et al. 2007; Galvis and Mojica 2007; Rodríguez et al. 2007; Baigún et al. 2013). Also, increasing recreational fisheries in the major developed areas of the upper Paraguay, the Orinoco, the San Francisco and the Paraná rivers has led to stakeholder conflicts that impact artisanal fisheries (Carolsfeld et al. 2003; Freire et al. 2016). This conflict is worsened when migratory fish species need to be managed under different legal frameworks across basins (Valbo-Jørgensen et al. 2008).

There is an institutional mismatch between the size of the fisheries and the capacity for surveillance, enforcement, and acquisition of harvest data, coupled with the absence of adequate management plans. The high dispersion of fisheries and open-access characteristics in most basins represents a major obstacle for assessment and regulations enforcement, particularly when the regulations are neither agreed nor accepted by fishers. Centralized government control policies with limited stakeholder's engagement (Barletta et al. 2010) have limited fishers´ participation, which is only an instructive or consultative relationship according to the continuum proposed by Sen and Nielsen (1996). Fishers´ participation and their knowledge have been historically rejected or ignored (Baigún 2015), even denying fishers the legitimate right to participate in management decisions. This problem has been exacerbated in those fisheries mostly exploited by indigenous people. Also, most fisheries exhibit outdated or incomplete legal frameworks focused on only fisheries issues. The main socioeconomic barriers relate to the underestimation of recreational fisheries impacts, weak inclusion of fishers in formal economic circuits, poverty and social marginalization of fishers, and poor economic profits and inequality in marketing chains. As inland fisheries lack economic visibility and remain poorly valuated, their local relevance has not been properly addressed (Benetti and Thorpe 2008). At the ecological and environmental level, landscape and waterscape degradation mainly produced by deforestation, construction of dams, and agriculture are all factors having the potential to alter fisheries sustainability and therefore to promote governance conflicts.

What Governance Should Mean in South American Large-River Systems

Governance priorities in large rivers should address the body of rules, traditions, norms, social networks, and regulations that allow key stakeholder involvement, participation, and interaction in the decision-making and implementation process. Ultimately, fisheries governance needs to assure economic growth, food security, employment, equitable access to resources, and poverty alleviation and to promote and integrate the sustainable use of fluvial resources and fishery resilience mechanisms.

According to Kooiman et al. (2005), governance could be envisioned as three interactive level processes that can be well identified and adapted to large-river fisheries. First-order governance relates to solving daily local conflicts and societal problems, which in fluvial systems involve making decisions about fishing areas, fishing satisfaction, conflicts between recreational and artisanal fishers, landing sites, market chains, and access and rules enforcement. Second-level governance corresponds to institutions and organizations that provide the framework within which first-order governance takes place by framing norms, laws, and agreements; solving problems; and creating opportunities. In South American large rivers, this level is often filled by government offices or institutions that lack the required expertise and are not well suited to accomplish this task. Moreover, fishers´ organizations are scarce and poorly developed. The third order or metagovernance is about the constitutive values, norms, and principles upon which governing activities and institutions are founded. Metagovernance reflects norms, ideas, and principles to improve governance at the first- and second-order levels and can also promote new directions and goals. At this level, fisheries governors need to make explicit their ideas and initiatives for discussion and evaluation and decide how, in practical terms, the ideas should inform collective decision-making and managing practices (Bavinck et al. 2005). This level is usually weak in fluvial fisheries, particularly when top-down conventional management is, in practice, lacking strong stakeholders' involvement and public. All these governance orders, however, should integrate a multiple-scale perspective. At the local scale, for instance, fishery systems are shaped by internal components and external stressors, but as the spatial scale increases, a broader array of actors, institutions, and stressors acting along the basin influence and increase governance complexity.

Good governance examples, however, are found in the Amazon basin where fishing agreements nested in comanagement were installed to limit commercial exploitation and to protect subsistence-oriented local fishers (Almeida et al. 2001, 2009; Silvano et al. 2009). As a result, overfishing trends were reduced, fish yields were increased, and stakeholder conflicts were minimized. Active fishers´ participation helped in recovering the iconic Paiche (also known as Arapaima) *Arapaima gigas* fishery (Castello et al. 2009). In the upper basin in Peru, territorial use rights for fisheries (TURFs), coupled with comanagement and community-based management, were successfully applied to protect main target species and, ultimately, local fishers' livelihoods (Anderson et al. 2009). Such cases demonstrate the critical relevance of strengthened local capacities based on incorporating traditional ecological knowledge, promoting rights of access to the resources, and protecting critical habitats for fish life cycles. Improvement of control and surveillance provided fishers with a general awareness of ecological and resource management concepts under a comanagement regime (Castello et al. 2009; A. Oliveira and L. Cunha, paper presented at the 8th biennial conference of the International Association for the Study of Common Property, 2000).

The Need for Adopting an Ecosystem-Based Governance Perspective

As large-river fisheries are strongly embedded within a watershed, including man-made and natural processes, governance should be visualized at multiple dimensions and scales, considering ecosystem and social factors as main interacting drivers. Preserving ecosystem health in large rivers emerges as one of the most critical outcomes of the governance processes for supporting long-term livelihoods and welfare conditions and maintaining the capacity to cope with external stressors from outside the fishery sector (Pasqual-Fernandez and Chuenpagdee 2013). In this context, the three-level governance systems should retain the ecological integrity of fluvial systems as the main basis for providing goods and services for a diverse spectrum of stakeholders and riverine communities. In the Amazon and the Orinoco basins, for example, interactions between people and the natural environmental vary spatially and temporally, usually involving complex governance processes (McGrath et al. 2008), and agriculture plays an important role during the dry season. Expansion of agriculture, however, could affect the forests as critical habitats for many valuable fish during the flooding season (McGrath et al. 2008). In the Magdalena River, floodplains occupation by ranchers have reduced fishing areas (Junk 2007), whereas in the lower Parana River, inner lagoons that are important rearing and fishing habitats have been isolated and converted to agriculture and cattle areas (Baigún et al. 2008).

River fragmentation by dams is probably the most pervasive factor that disrupts fluvial ecological integrity and affects fluvial fisheries. In the upper Parana basin, reservoir formation has reduced fish yield and decreased stocks of large migratory species having high commercial and sporting value, thus impacting fishers´ socioeconomic conditions (Agostinho et al. 2003; Hoeinghaus et al. 2009). Similar patterns were noted in the San Francisco River (Sato and Godinho 2003). The loss of ecosystem health in fluvial systems could have direct impact on rural fisheries where fishing strongly contributes to food security. The deterioration of human, natural, financial, social, and human capital as part of livelihood assets could compromise the resilience of communities to cope with severe or irreversible impacts. The above examples point out the need to balance cost and benefits for different stakeholders in large rivers, integrating man-made infrastructure with fishers' needs, demands, and rights as part of main governance outcomes.

Ecosystem-based governance in fluvial systems should be strongly related to the application of an ecosystem-based approach for fisheries management (EAF). The EAF recognizes the human component as one of the main pillars for governance (De Young et al. 2008), giving stakeholders´ participation a central role. An ecosystem approach oriented to fisheries thus provides a powerful framework to assess and recognize main gaps and limitations in solving social, economic, fishery, environmental, and institutional problems that shape fishery governance. In addition, it requires and promotes the interaction across different sectors that use and could impact water resources. Unfortunately, the EAF concept is still poorly developed in South American large rivers and is not being yet considered by management agencies as a desirable goal to achieve better governance (Barletta et al. 2016).

Conclusions and Future Directions

Installing better governance processes in South American large rivers is challenging managers and other main stakeholders. Suitable governance practices in South American rivers have not yet been underpinned by the application of strong social, economic, institutional, and environmental criteria and practices. Poor governance results can be attributed to visible problems associated with increasing basin fragmentation, pollution, and overfishing, but social, economic, and institutional problems have remained less detectable or even not well perceived by government and other stakeholders. The importance of the social dimension for small-scale fisheries governance cannot be emphasized enough (Arthur et al. 2016). Most tropical small-scale fishers are comprised of poor and marginalized people (Pauly 1997), and in several South American basins, large populations suffer from inadequate nutrition and exclusion of their lands and lack the most basic health services, social rights, and education (Chapman 2008). Exclusion of the people that depend on fisheries from political decisions weakens the governance process (Friend 2009) and reduces collective efforts to participate in sustainable resource management (Ratner and Allison 2012). Management approaches that are centrally controlled with little or no stakeholder involvement still remain a main obstacle to improving the governance processes by reducing the possibility of sharing responsibilities and decisions with management agencies. This is due to their inability to cope with the complexity of fluvial fisheries, which are driven by environmental features, the interaction with fishing activity, and the lack of support from the people dependent on the fishery.

Accelerated development of artisanal fisheries in South American rivers, increasing man-made impacts, and climate change all could impact rivers' ecological integrity and necessitate improving governance conditions in river fisheries. Moving to an ecosystem-based perspective to promote better governance processes, however, will require a long effort in recognizing different stakeholders' visions and problems as the basis to start discussing actions and potential solutions for new governance paradigms (Chuenpagdee and Jentoft 2013). Several general measures inherent to small-scale fisheries can be applied to reduce governance barriers in South American floodplain river fisheries (Table 1). For example, envisioning fluvial fisheries as providing highly valuable ecosystem services and not as commodities and understanding their irreplaceable social benefits represent a seminal concept to improve fisheries governance and maintain feedbacks between fisheries, ecosystem productivity, and aquatic biodiversity (Beard et al. 2011). In turn, comanagement concepts and participative management policies need to be considered as a critical part for improving an ecosystem-based governance approach. However, rural fisher communities still have difficulties in self-organization and achieving collective actions, which are strong limitations to their participation in governance processes (Béné 2008). In this context, management agencies need to stimulate consensus, collective action, and recognition of fishers´ rights and demands. Clearly, new institutional and legal arrangements involving experts in planning, adaptive management, and social skills are needed to foster not only stakeholder participation in policy making, but also addressing learning, inclusiveness, and partnership as part of new interactive management agendas (Bavinck et al. 2005). Recognition of users´ tenure and rights-based approaches and co-

Table 1.—General measures for improving fisheries governance in South American large rivers.

Dimension	Measures
Fishery/ management	Develop reliable fishery information systems to aquire basic data. Identify indicators of fishery sustainability and related reference point system based on scientific and fishers' ecological knowledge. Develop and apply a community-based approach expanding benefits at social and environmental levels. Develop management agreements for common regulations, research, and monitoring programs for main target species in transboundary basins. Develop an ecosystem approach to fisheries management to promote fishery, environmental and social sustainability. Envision large-river fisheries as a long-term valuable ecosystem service strongly dependent on fluvial ecological integrity.
Social/ economic	Aquisition of informatimon oriented to capture social and economic trends. Develop appropriate mechanisms for partnership, empowerment, and inclusion of stakeholders in management plans. Work with governmental and nongovernmental institutions to improve social and economic conditions and recognition of fishers' rights. Develop and promote fishers´ organizations to achieve better and fairer trade conditions.
Institutional	Promote capacity building and training and reinforce management agencies. Promote stakeholders' participation, consultation, and comanagement practices for the formulation and implementation of fisheries management plans. Develop participative and adaptive management plans integrating the needs, interests, and demands of a broad spectrum of stakeholders related to fisheries sustainability. Promote a sound revision and update of legal frameworks stimulating the inclusion of norms associated to an ecosystem-based approach. Develop appropriate management policies to account for different fishing activities of the most highly vulnerable fishers groups.
Ecological/ environmental	Integrate fisheries in multipurpose land and water use management and raise awareness about fluvial ecological processes and factors that govern fish production and biodiversity conservation. Develop research programs oriented to identify and preserves critical migratory corridors, spawning and rearing habitats that require specific management, and conservation measures. Preserve functional processes based on flood high-low water pulses and related to floodplains and channels connectivity as key factors to support fisheries sustainability.

management and empowerment of the poor and more vulnerable stakeholders will also play a critical role in promoting new governance scenarios (Franz et al. 2016). How new institutional, legal, and socioeconomic frameworks can be accommodated to shape better processes based on considering environmental and social sustainability will be main goals and challenges for future scenarios in large South American river basins.

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Recreational Fishing and Territorial Management in Indigenous Amazonia

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Abstract.—At least 73% of Brazilian indigenous lands suffer one or more pressures or territorial threats, and 55% of federal conservation units do not have approved management plans. These protected areas encompass more than 40% of the Brazilian Amazonia. Official governmental management programs are not adequately supported and lack consistent monitoring and surveillance. Protected areas are under immense pressure from mining and commercial fishing and, more recently, from recreational fishing tourism. Even though recreational fishing in these areas is legally possible, it has been initiated without due consultation with the affected communities, disregarding the International Labor Organization's Indigenous and Tribal Peoples Convention (No. 169). Also, recreational fishing is being undertaken in a competitive model with no assessments of feasibility or assurance of socioenvironmental benefits. The community-based project of recreational fishing tourism implemented in the Marié River resulted from an cross-sectoral partnership supported by government and nongovernmental organizations based on the indigenous communities' interest to develop an economic activity to ensure quality of life. The partnership also developed a joint monitoring and management program to protect the livelihoods and collective interests of indigenous peoples with emphasis on food security. The recreational fishing tourism in the Marié River became an opportunity for the indigenous communities to lead the governance, management, and conservation of their traditional territory.

Introduction

At approximately 710,000 km^2, the Negro River basin is the largest basin of black water in the world. The peculiar color is due to a specific geochemistry and low levels of sediments, nutrients, and pH. These features result in a river of low biomass with very high species diversity, with more than 450 fish species identified of which 40 species are endemic (ISA 2009). Characterized by a wide variety of upland and floodplain forest landscapes (Goulding et al. 1988), the basin has been managed by traditional systems of use, according to the indigenous knowledge of the people who have inhabited the region for more than 3,000 years (Cabalzar and Ricardo 1998). The basin is one of the most conserved in Amazonia, with less than 1% deforestation due to several factors related to environmental characteristics, a history of traditional occupation of low impact, and, more recently, the recognition of protected areas (PAs) for 62% of its length (Raisg 2015)[1]. Protected areas are localities with relevant socioenvironmental importance and, therefore, are supported by a specific legal statute relative to their management and use. These areas are created under the principle of conservation and tenure rights regarding sustainable use or full protection (Federal Law No. 9,985/2000,

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[1] For further information, see RAISG, http://raisg.socioambiental.org/.

which established the National Program for the Conservation Units).

The deforestation rates in Amazonia have been estimated, and it was confirmed that the indigenous lands are the most conserved areas (Fonseca et al. 2015). These results reinforce the studies that indicate the fundamental role of the indigenous peoples at preserving the forests and biodiversity therein, both by traditional management and through surveillance by living in their territories (Toledo and Barerra-Bassols 2008).

The complex of indigenous lands and conservation units in the upper portion of the basin and the establishment of a mosaic of PAs in the lower region has helped conserve the natural resources. However, in a large portion of the middle Negro River region, the land's rights are yet to be defined, which exposes this region to greater fishing pressure. Indeed, the whitewater tributaries (nutrient-rich soil and high biomass) and the large number of lakes in this region generate important fish reproduction and nursery sites. This middle Negro River region (Figure 1) is the primary source of fish in the basin (Amaral 2010), and it is also considered the most important area for recreational fishing in the Brazilian administrative state of Amazonas (Batista 2001; Menezes 2005).

The lack of planning or regulation of commercial and recreational fishing activities allows overlap and increases conflicts over resource access (Begossi 2004; Sobreiro 2007). Although recreational fishing generates employment, the revenue is concentrated with nonlocal or even foreign agencies that ignore their socioenvironmental responsibilities. Yet the region receives an increasing number of recreational fishing tourists (Zeinad 2003; Lopes 2010; Barra and Dias 2013). Despite the lack of systematic monitoring and data collection, the impacts of recreational fishing are a major concern regarding conservation (Cooke and Cowx 2004; FAO 2012).

The Socioenvironmental Institute (ISA) has engaged with local stakeholders to build

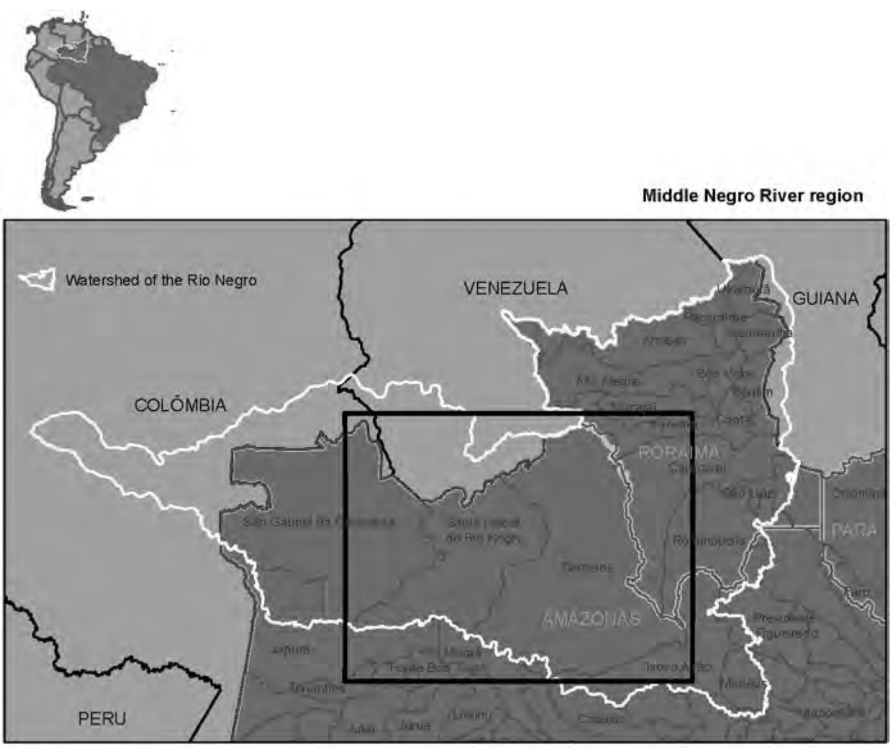

Figure 1.—Middle Negro River region.

cross-sectoral forums among government agencies, indigenous communities, and fishing sectors to develop fishery management proposals. Participatory surveys and workshops were promoted to develop recommendations for zoning areas and regulating fishing activities (Alves et al. 2012). Despite the State of Amazonas' governmental responsibility to ensure sustainable fisheries, none of the public policies or managing measures was implemented. Both recreational and small-scale commercial fisheries occur haphazardly, without fish stock assessments, monitoring, or surveillance.

The pressure on fish stocks has reduced the availability of resources and stimulated the advancement of recreational fishing in other preserved and protected areas, such as the Marié River, indigenous land in the transition zones between the middle and upper Negro River. The recreational fishing tourism in the Marié River started illegally through negotiations and cash payments to some indigenous leaders, dragging communities into the competition between tourism companies over exclusivity of the fishing area (Barra and Crepaldi 2014).

Despite conflicts, the Marié River provided an opportunity to set an innovative model of inland fisheries management once land rights were defined. Fishery management in the Marié River was developed under a community-based project of recreational fishing tourism.

Based on this case study, this paper discusses recreational fishing tourism on indigenous lands and traditional territories as an example of low-impact activities that might provide an opportunity for long-term monitoring and management of PAs, with emphasis on food security and livelihood assurance.

Indigenous Lands' Legislation and Challenges for Management

The Brazilian federal government has the tenure rights of the indigenous lands, but the indigenous peoples are entitled to the permanent holding of the land and the exclusive use of the assets derived from soil, rivers, and lakes within these territories (Constitution of the Federative Republic of 1988, articles 231 and 232). It is the Brazilian government's responsibility to enhance local culture, traditions, organizations, and livelihoods, and to support initiatives headed by the indigenous peoples to promote the well-being of their communities.

The National Policy for Environmental and Territorial Management of the Indigenous Lands (PNGATI; Brazil 2012) regulates the insertion of economic activities and tourism in indigenous lands if these activities contribute to the territory administration and to the sustainability of families, provided that (1) they are of collective interest, (2) they are environmentally safe, and (3) the livelihoods and cultural traditions are respected. The PNGATI recognizes the right of the indigenous communities to promote economic activities and establish partnerships, settling previous doubts that stemmed from the Federal Constitution and the Statute for Indigenous People (Federal Law No. 6,001/1973).

As of June 2015, a federal normative for tourism on indigenous lands (FUNAI Normative No. 3 of 2015) was approved for the the development of activities according to a community-based model and after performing the required socioenvironmental impact studies. The indigenous communities are autonomous and will define the activities that are permitted in their traditional territory. The Federal Indian Affairs Agency (Fundação Nacional do Índio; FUNAI) and other government agencies are in place for supporting, instigating, and following the activities to assure socioenvironmental security and the respect of collective and tenure rights.

According to the recent legislation, recreational fishing tourism, although legal, may be implemented only if it aligns with the interests of indigenous communities and is preceded by research that studies the potential impacts of fishing.

The government is responsible for the management and support of traditional and indigenous communities to assure sustainable use of the PAs. These correspond to more than 40% of the Brazilian Amazonia. However, it costs approximately US$200,000 annually to manage a PA in Amazonia[2]. The official management pro-

[2] According to the Amazon Region Protected Areas Program of the Ministry of the Environment (www.mma.gov.br/port/sca/arpa/).

grams are not adequately supported. At least 73% of Brazilian indigenous lands suffer from some kind of pressure or territorial threat while 55% of federal conservation units do not have approved management plans (Raisg 2012).

Considering that natural resource conservation is not a priority for the Brazilian government, tourism provides an opportunity to generate income to invest in natural resources monitoring, indigenous land management, and surveillance and to be used for improving communities' infrastructure. In this sense, economic activities of low impact and high aggregate value, such as recreational fishing tourism, may contribute to the conservation of these areas.

The Marié River Experience

The Marié River is an important traditional usage area comprised of 15 indigenous communities and more than 250 families that value food security, cultural traditions, and stable livelihoods. The area is also central for economic activities such as small-scale commercial fishing (Barra and Crepaldi 2014).

The diet of the Negro River peoples is based on fish, as a main source of protein, and manioc, a tuber (Begossi 2004). The traditional knowledge responsible for management of fishing resources was deeply affected by colonial occupation since the 18th century, forcing migration to support the rubber trade (Cabalzar and Ricardo 1998). Fish shortages increased when high-impact fishing gears were introduced, along with increased commercial fishing pressure and illegal natural resource-use activities like mining.

To assure that the rights of indigenous peoples were recognized and to deal with the new required dynamics, indigenous communities created nongovernmental representative organizations in the 1980s and 1990s. These associations operated similarly to a parliamentary system that brought leaders together to discuss and make decisions for the collective well-being. The first indigenous organization created in the Negro River basin was the Association of Indigenous Communities of the Lower Rio Negro, which represents the communities that traditionally use the Marié River.

However, the lack of public policies and basic human rights, such as health and education, and the absence of management and conservation programs allow external pressure over indigenous communities and the natural resources. In the search for a better quality of life, the indigenous leaders are pushed to negotiate with external stakeholders without any guarantee of sustainability of the proposed economic activities, often resulting in restricted or individual benefits. It is in this context that recreational fishing was initiated in the Marié River in 2010.

Providing excellent recreational fishing[3], the Marié River was invaded by companies that operated without any socioenvironmental management plans. These companies signed illegal and simultaneous contracts with multiple indigenous leaders in search of exclusivity of the fishing area. Conflicts emerged among the indigenous communities and the situation was denounced to the Federal Prosecution Service (Ministério Público Federal; MPF).

In 2013, after a successful coordinated effort by FUNAI and the Brazilian Army, the recreational fishing companies were removed from the indigenous land. Subsequently, MPF published a recommendation to prohibit any recreational fishing activity in Marié River until FUNAI and the Brazilian Institute of Environment and Renewable Natural Resources (IBAMA, Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis) performed socioenvironmental impact studies that evaluated the viability of the activity. This judicial action was crucial to the regulation process once the government agencies do not have the necessary financial and human resources to promote management in Amazonia (Barra and Crepaldi 2014).

At this point, an intersectorial strategy involving indigenous organizations, their part-

[3] The International Game Fish Association world record of the Speckled Peacock Bass (also known as Speckled Pavon) *Cichla temensis* was caught in the Marié River.

ners, and government agencies was initiated to promote fisheries and regulate the recreational fishing tourism. The Marié River's indigenous communities assembled and evaluated the suitability and feasibility of recreational fishing as an economic alternative for their sustainability.

The Federal Indian Affairs Agency established technical cooperation with IBAMA and ISA to work with the indigenous organizations and communities to regulate the recreational fishing, observing four ongoing steps:

- Consultancy: broad consulting to understand and support communities' interest to permit recreational fishing tourism (or any other economic alternative) in their territory, assuring active and collective participation in the decision making.
- Socioenvironmental studies: assessment of fish stocks and evaluation of the suitability and feasibility of recreational fishing under an integrated management plan of the indigenous lands, carried out by communities and according to their livelihoods.
- Monitoring and evaluation: implementation of continuous and participatory monitoring programs of the activity for adjustments during the entire process.
- Intersectorial cooperation: technical cooperation and commitments established among communities, government agencies, and other partners to promote a community-based project.

The results confirmed the high potential for recreational fishing and fisheries interaction to respect and to preserve the indigenous livelihoods (Barra and Crepaldi 2014). The process of consultancy and associated workshops were important steps to improve communities' governance over their traditional territory, especially considering (1) the fishing management plan identified the areas and rules for the different fishing activities with emphasis on cultural traditions, food security, and conservation; and (2) the protocols defined to assure all decisions were made according to collective interests.

Previous studies of tourism activities on indigenous lands have identified that any initiative should be a component of an integrated management plan that ensures community benefits and respects livelihoods (Silva 2008; Irving 2010). In spite of the complexity of promoting intercommunity agreements, the external threats and pressure over resources might be transformed into an incentive to meet and discuss proposals.

The sociocultural perspective encompasses the socioeconomical dynamics of fishing and how recreational fishing would impact it. In this sense, during broad community meetings and family surveys, the elements of the fisheries management plan were discussed to strengthen customary rules, to incorporate new elements for managing recreational fishing tourism, and to ensure that the plan was a feasible economic alternative for collective development (Barra and Crepaldi 2014).

A term of reference with all required criteria was formulated by the indigenous communities and their organizations with technical support to call for proposals from operators interested in conducting tourism in partnership. The innovative project started in 2014 with a community-enterprise contract that contemplates and finances

- collective investments in the communities, and a hiring and capacity-building program of local labor;
- maintenance of a comanagement program that involves the monitoring of the fishing activities and surveillance of the territory;
- restricted scale for a low-impact operation (i.e., fly-fishing catch and release); and
- annual evaluation expeditions accompa nied by appropriate government agencies.

The community-based project of recreational fishing tourism in the Marié River improved indigenous governance over their territory because the activity promoted surveillance and fisheries monitoring under the management plan implemented by the indigenous organization. After 2 years of the project, fish stocks are recovering, as reported by the indigenous leaders. Also, environmental balance is confirmed by IBAMA (Crepaldi and Machado 2014, 2016). From the social perspective, communities are improving their collective infrastructure and a few indigenous families that previously moved into urban areas looking for a better quality of life have returned to their communities.

Final Considerations

Clear territorial rights are crucial for participatory fishing management and to promote agreements when conflicts arise. Also, engaging indigenous and traditional people in fish monitoring programs promotes continuous data collection, which otherwise would be impracticable in Amazonia. In this sense, recognized PAs are strategic for conservation.

The Marié River case study highlights the importance of participatory processes that actively involve stakeholders so that the commitments and responsibilities are shared from the beginning. This is not enough to avoid issues or difficulties as indigenous communities adapt socially and economically for tourism. Therefore, it will ensure that the challenges are identified and measured, regarding the adequate time for each stage of the process to achieve the conditions for effective comanagement under all perspectives.

Once the assessment studies are performed and the indigenous communities understand all aspects of recreational fishing tourism, it is necessary to develop programs for monitoring and comanagement. Despite a possible partnership with government agencies, these programs must be adequately funded and independent from governmental programs, which are restrictive and highly sensitive to the political context.

Sustainable economic activities must promote (1) the interest and continuous participation of the indigenous communities during the whole process, (2) the involvement of governmental agencies, (3) the necessary studies to assure the socioenvironmental feasibility of the activity, and (4) the development of the activities as part of the integrated management plan of the territory, which includes monitoring and surveillance measures. To ensure those aspects are incorporated, specific mechanisms should be developed by the stakeholders that respect livelihoods and proper social organization frameworks of the indigenous communities.

Strategic initiatives that promote traditional livelihoods and economic prosperity under communities' governance structures are promising for long-term monitoring and management of PAs (Barra and Crepaldi 2014). In this sense, recreational fishing community-based tourism may contribute to fish stocks' conservation, thus ensuring food security and the sustainability of indigenous communities in Amazonia.

Acknowledgments

The Socioenvironmental Institute (Instituto Socioambiental; ISA) is a nongovernmental organization registered under Brazilian law as a public interest civil society organization. ISA was founded in 1994 with the purpose of developing solutions for social and environmental problems, especially related to the well-being of indigenous and other traditional people. ISA promotes cross-sectoral partnerships and produces research, implements projects and programs for socioenvironmental sustainability, valuing the cultural and biological diversity of Brazil. This chapter has important contributions from Ana Paula Caldeira Souto Maior, a lawyer from ISA, and Daniel Crepaldi, an analyst from IBAMA. The ISA and IBAMA have performed the impact studies in the Marié River in cooperation with FUNAI and still work in partnership with indigenous communities on management of the project.

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Integrated Swamp Management to Promote Sustainability of Fish Resources: Case Study in Pampangan District, South Sumatra Province, Indonesia

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Abstract.—Pampangan District is a floodplain area, containing 21 distinct swamps characterized by seasonal shifts in the aquatic and terrestrial environment. During the wet season, the floodplain is covered by water with a depth of 1–4 m, whereas during dry season it becomes dry land. Local people living around the swamps have seasonal activities as fishers during the wet season and as rice farmers during the dry season. The average gross income is 15,041,000 Indonesian rupiahs (Rp) per wet season from fisheries and Rp 10,445,000 per dry season from rice farming. The swamps in Pampangan District are managed in an integrated manner based on local regulations. During the wet season, the water bodies are managed as common property resources, wherein all community members are allowed to exploit fish resources. During the dry season, the landowners claim their plots of rice field to cultivate rice. However, some small pools within the rice field areas are inhabited by several species of fish that are kept as broodstock to supply young fish for the next wet season.

Introduction

Indonesian inland waters cover around 54 million ha, of which 12 million ha consist of rivers and floodplains, 39 million ha consist of swamps, and 2 million ha consist of lakes and other water bodies. These water bodies support the livelihoods of poor, rural people. One floodplain area, the Pampangan District (Anonymous 2005), is characterized by seasonal shifts between aquatic and terrestrial environments. During the wet season, the floodplain is covered by water to a depth of 1–4 m, whereas during the dry season, it becomes dry land. Local people living around the swamps have seasonal activities as fishers during the wet season and as rice farmers during the dry season.

Muthmainnah (2013) shows that fishing plays a major role in the social and economic development of the rural poor because it is an important occupation for a large number of rural people living in the floodplain of the Pampangan District. In the dry season, people prepare the floodplain and plant rice by transplanting seedlings, which are raised in a nursery. When the water level of the Komering River rises and overflows its banks, the rice fields become flooded and eventually rice may be harvested from a canoe. The deepest part of swamp in the rice field is called lebung (pool) and is permanently flooded, either as a natural or man-made pool.

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Pools usually function as fish habitat during the dry season and are utilized as traps where fish are concentrated and easily caught by fishers. Pools have high biodiversity: black fish species (those living in swamps) include snakeheads *Channa* spp., Bronze Featherback *Notopterus notopterus*, Climbing Perch *Anabas testudineus*, and gourami *Trichogaster* spp.; some species of riverine (white) fish are also found in pools, such as *Puntius* spp. and *Osteochilus* spp.

In the Pampangan District, a specific local regulation states that during the dry season fishers can catch fish in pools only of marketable size, whereas small fish must be released to the surrounding swamp waters. Some pools are also protected as small fishery reserves.

Thus, the pools provide key habitats that provide food to local communities. However, water must be managed appropriately among all users. The conflict between inland fishers and other sectors can be minimized if there is communication among stakeholders about their plan for water utilization. This communication will also improve the access to reliable fish and rice harvest data, thus enhancing monitoring and conservation programs.

This research focused on how integrated management in swamp utilization can promote the sustainability of fish resources in the Pampangan District, South Sumatra Province, Indonesia.

Methods

Field research was carried out by direct observation on swamp areas and interviews with fishers, rice farmers, and social leaders from January to December 2012 in Pampangan District, Ogan Komering Ilir Regency, South Sumatra Province, Indonesia (Figure 1).

The quantitative data collected included fish catch per unit swamp (kg), fish price (Indonesian rupiah [Rp]), rice field area (ha), rice production (metric ton/ha), and rice price (Rp). Data were collected through questionnaires filled in by randomly selected respondents consisting of 102 fishers and 57 rice farmers. Additional information was also collected from local government officials.

Results

Water-level recordings showed that during the rainy season (December to May), the swamp water depths are higher than 1 m and almost all swamp areas are inundated, but during the dry season (May to November), the water level decreased to less than 50 cm (Figure 2). Rice farmers begin to cultivate the paddy fields in May, and seedlings are moved into the paddy field in June. The paddy harvest is done in November, when the water level rises and when there is no more paddy cultivation.

In Pampangan District, among those interviewed, 57 people worked as rice farmers and 102 people worked as fishers. Some of these interviewees alternated between farming and fishing, but some fishers did not have land for rice cultivation so only fished. Commonly, the fishers work in groups to exploit fish resources in specific areas that are defined by the local government.

Differences in number of fishers, income, and total catch among swamps were found (Table 1). Total catch ranged from 937 kg in Muara Deles 4 to 30,788 kg in Rasau Jarang; the highest catch per fisher was 6,117.5 kg from Lebak Semunting. The swamp with the lowest total catch, Muara Deles 4, was fished all year long but by only two fishers.

During the dry season, about 110 ha of shallow areas are utilized for rice cultivation (Table 2). There were 57 farmers involved, with a total rice production of 111 metric tons. We assumed that 1 kg rice was valued at Rp 5,000, and therefore, the average income of rice farmers was Rp 10,445,000 per season. Rice production per hectare was only about 1 metric ton in all villages.

Discussion

In Pampangan District, the swamps are managed in an integrated manner based on local wisdom. During the wet season, the water bodies are managed as a common property where all community members are allowed to exploit fish resources. During the wet season, however, the allocation of selected fishing grounds by

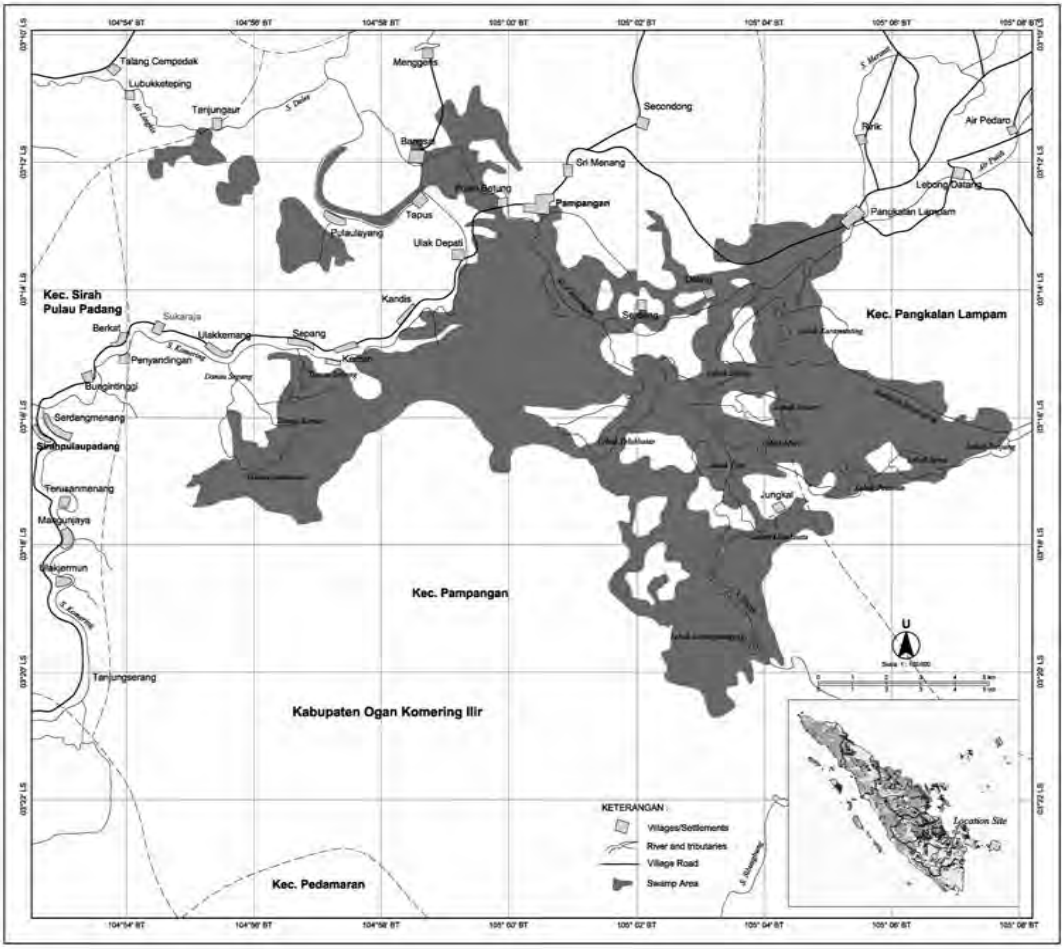

Figure 1.—The map shows the location of the Pampangan District, Ogan Komering Ilir Regency, South Sumatra Province, Indonesia, where field research was conducted between January and December 2012.

the local government is determined by an auction system whereby groups of fishers bid for the right to fish.

During the dry season, the permanent owners claim their plot of rice field for cultivating rice. However, some small pools within the rice field areas are still inhabited by several species of fish that can be used as broodstock to supply young fish for the next wet season. This result shows that the people living around the swamps in Pampangan District understand conservation and are planning for sustainable fisheries. Mustafa and Halls (2006) found a similar result in Bangladesh where groups of poor fishers were practicing sustainable fisheries management by establishing fish sanctuaries, controlling the use of destructive fishing gears, and banning fishing during the spawning season. In the Bangladesh study, annual fish production (in kg/ha) increased on average by 13% per year. Waluyo and Supriyo (2006) in adjacent swamp areas introduced a new rice cultivar and new technology resulting in higher rice production (3.6 metric tons/ha), slightly higher than the average rice production in South Sumatra Province of 3.2 metric tons/ha (Anonymous 2012) and much higher than the 1 metric ton/ha found in this study.

The average individual gross income was Rp 15,041,000 per season from fisheries, with

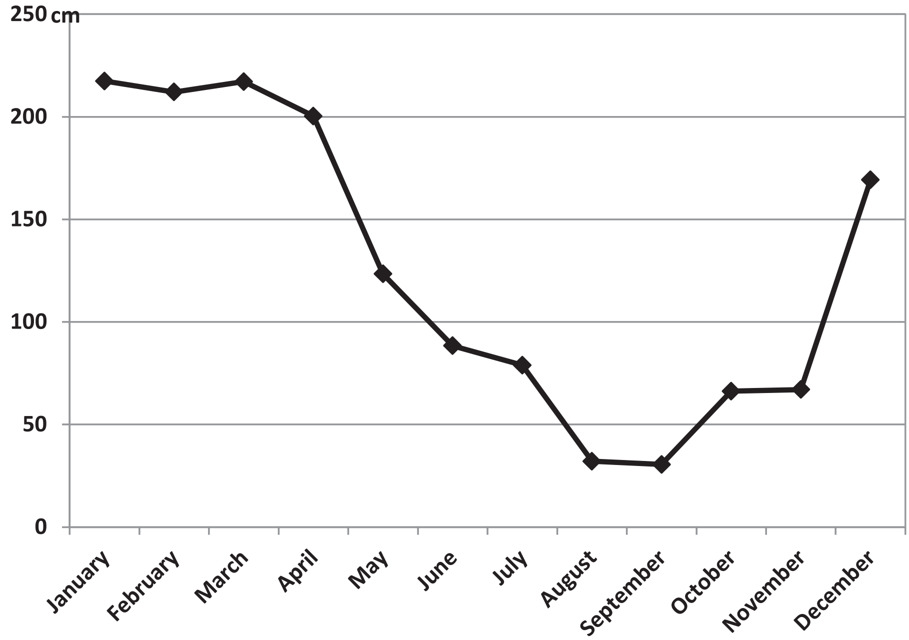

Figure 2.—Water level record (cm) in Pampangan District during 2012.

Table 1.—For each swamp located in Pampangan District, the total catch (kg), number of fishers, the total number of months fished, and the annual income of individual fishers is summarized. Average fish price = 7,175 Indonesian rupiahs (Rp)/kg.

No.	Name of swamp	Total catch (kg)	Number of fishers	Total months of fishing per year	Income per year (Rp) of each fisher
1	Lebak Semunting	12,235	2	8 (June–January)	43,890,000.00
2	Lebak Deling	12,954	7	8 (June–January)	13,277,142.86
3	Lebung Asem	1,500	7	7 (July–January)	1,537,142.86
4	Kedukan Kiaagung	2,492	2	8 (June–January)	8,940,000.00
5	Lebak Gabus	18,987	7	11 (February–December)	19,461,428.57
6	Rasau Jarang	30,788	10	11 (February–December)	22,090,000.00
7	Sengah Buye	8,683	4	10 (March–December)	15,575,000.00
8	Keliling Pulau	20,307	10	9 (April–December)	14,570,000.00
9	Lebak Gelam	5,143	3	8 (April–November)	12,300,000.00
10	Lebak Pinang Boreng	3,458	3	8 (May–December)	8,270,000.00
11	Lebak Tiris	10,704	7	9 (April–December)	10,971,428.57
12	Sebumbung	7,568	4	9 (April–December)	13,575,000.00
13	Lebak Murti	6,182	5	8 (May–December)	8,870,000.00
14	Lebak Danau	8,649	5	8 (March–October)	12,410,000.00
15	Lubuk Sekayan	3,596	2	10 (February–November)	12,900,000.00
16	Muara Deles 4	937	2	Whole year	3,360,000.00
17	Lebak Kuro	9,631	4	Whole year	17,275,000.00
18	Lebak Camang	10,872	4	9 (April–December)	19,500,000.00
19	Lebak Lepok	7,966	3	8 (January–August)	19,050,000.00
20	Sematang Bunder	7,443	2	11 (February–December)	26,700,000.00
21	Lebak Perompong	14,230	9	9 (April–December)	11,344,444.44
				Average income of individual fisher by swamp	**15,041,000.00**

Table 2.—For each village, we estimated the income of each farmer per season by multiplying the total production (metric ton) by its value in Indonesian rupiahs (Rp; 1 kg is valued at Rp 5,000) and divided by the number of farmers in the village. We also provide the total area of Pampangan District rice fields in each village.

No.	Village	Rice field (ha)	Number of farmers	Total production (metric tons)	Income of each farmer per season (Rp)
1	Ulak Kemang Induk	10	4	10.30	12,875,000.00
2	Ulak Kemang Baru	5.5	3	6.10	10,166,666.67
3	Sepang	10	6	9.45	7,875,000.00
4	Keman	9	5	9.15	9,150,000.00
5	Keman Baru	4	2	3.80	9,500,000.00
6	Ulak Pianggu	5	2	5.50	13,750,000.00
7	Kandis	11	6	11.00	9,166,666.67
8	Ulak Depati	7	3	7.10	11,833,333.33
9	Tapus	12	7	12.30	8,785,714.29
10	Pulau Layang	9	5	8.90	8,900,000.00
11	Kuro	6	3	6.20	10,333,333.33
12	Bangsal	5	3	4.90	8,166,666.67
13	Menggeris	5	2	5.10	12,750,000.00
14	Pulau Betung	6	4	6.30	7,875,000.00
15	Serdang	2	1	2.20	11,000,000.00
16	Serimenang	3	1	3.00	15,000,000.00
		Average income of individual rice farmer per village			**10,445,000.00**

an average period of fishing of 9.2 months (Table 1) and Rp 10,445,000 per season from rice farming (7 months for a season of paddy cultivation). The duration of the fishing period depends on the depth of swamp. In the shallow swamp of Lebung Asem, the fishing period only lasts 7 months, while in the deepest swamps (Muara Deles 4 and Lebak Kuro), the fishing period is almost year-round. This fact demonstrates the importance of fishery activities to earn income to meet their day-to-day life.

The current study showed that the people around the swamp areas understand integrated management of their resources based on seasonal water availability and available resources. Problems may emerge in the long term due to increasing human population in the area and increased competition for land, water, and fishery resources. Local government needs to continue local fishing regulations, but more formal regulations on exploiting wild stock may need to be established.

Population impacts on the environment is primarily through the use of natural resources and production of wastes, loss of biodiversity, air and water pollution, and increased pressure on arable land (Sharma 2008). Fishing communities often face unique challenges to social and economic stability as they rely on one particular natural resource for income and employment; fishers are often characterized as economically impoverished and politically marginalized (Bailey and Pomeroy 1996).

Ita (1993) stated that the relationship between poverty and property rights over natural resources is complex. Poverty can lead to a high dependence upon natural resources. Exclusion from crucial resources following changes to property rights regimes can act as the main catalyst for increasing deprivation and vulnerability of poor households. Accessing common property resources, local regulations, and conservation considerations are main elements in sustainable development. The traditional resource sharing system in Pampangan District guaranteed continued access to food (i.e., fish and rice) for vulnerable members of the community.

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Ecosystem Approach to Fisheries and Aquaculture in Southern Lake Malawi: Key Challenges during the Planning Stage

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Abstract.—This paper presents key challenges and lessons experienced during the ecosystem approach to fisheries and aquaculture (EAFA) planning process for the southern Lake Malawi, Mangochi district. This is in response to a near collapse or serious decline of chambo (*Oreochromis* sp.) harvests in the fishing area due to various ecological and socioeconomic problems such as overfishing, weak enforcement, habitat degradation, conflicting management policies, and deforestation. The estimated annual chambo harvest recorded between 4,000 and 5,000 metric tons in the early 1980s from southern Lake Malawi has now declined by almost 50%. The reduced catch represents a loss of about 2×10^9 Malawi kwacha, which is approximately US$5.5 million using 2012 chambo beach prices. The decline in both catch and revenue, therefore, justifies the need to identify policy and governance reforms for recovery and sustainable management of the fishery. Stakeholders recommended the development and implementation of an EAFA plan to guide rebuilding the chambo populations. Aquaculture development within the fishing area was also taken into account for increased supply of farmed chambo for food, nutritional security, and improved livelihoods of the local communities. Key challenges and lessons from the EAFA development process include setting objectives, defining boundaries, extent of consultations, commitment of stakeholders, stakeholder participation, overdependence on fishing, open-access nature of the fishery, conflicts, and limited availability of data. The ecosystem approach to fisheries and aquaculture is a suitable management approach as it considers varied socioeconomic and ecological objectives of a user community.

Introduction

There is an emerging interest in the application of an ecosystem approach to fisheries and aquaculture (EAFA) by various countries as a result of continued declining capture fisheries resources. Malawi is one of the countries in Africa that has developed an EAFA plan to guide management of fishery resources in the freshwater ecosystem of southern Lake Malawi, mainly due to the serious decline of the high-value chambo (*Oreochromis* sp.), a cichlid. The estimated annual chambo harvests that were between 4,000 and 5,000 metric tons in the early 1980s from southern Lake Malawi have now declined to less than 2,500 metric tons (FAO 1993; Bulirani et al. 1999; Banda et al. 2005; GoM 2014). The main reasons for the chambo decline include overfishing, habitat degradation, human population growth, and climate change and variability (Banda et al. 2005). The reduced catch represents a loss of about 2×10^9 Malawi kwacha, which is approximately US$5.5 million using 2012 chambo beach prices (GoM 2012). The decline in both catch and revenue, therefore, justifies the need to identify policy and governance reforms for recovery and sustainable manage-

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ment of the fish and fisheries to improve livelihoods of the user community.

The ecosystem approach to fisheries and aquaculture is defined as "a way of managing fisheries and aquaculture that balances the different objectives of society (e.g., ecological and economic objectives) by applying an integrated approach across geographical areas that reflect natural ecosystems" (Staples and Funge-Smith 2009:6). The ecosystem approach adopts the concept of sustainable development that has eventually replaced previous policies of development that focused on economic growth (FAO 2009). Sustainable development is a "process for finding a balance between ecological well-being and human well-being so that development does not destroy the natural resource base on which it is dependent, but avoids over-protection of resources that prevents rational development" (FAO 2009:6).

The ecosystem approach to fisheries and aquaculture can be applied as a means to achieving sustainable development, contributing to food security and human development while maintaining environmental integrity and enhancing social well-being by reducing intra- and intersectoral conflicts in both a participatory and consultative manner with the engagement of relevant stakeholders (FAO 2009). It is recommended that when applying EAFA, the Code of Conduct for Responsible Fisheries (CCRF) should be considered as well (FAO 1995). The CCRF provides a framework for responsible fisheries, whereby the objectives of responsible and sustainable fisheries and aquaculture can be implemented at both local and national levels (FAO 2009). This paper outlines key challenges encountered during planning of an EAFA for the southern Lake Malawi. Specifically, it draws major lessons from the formulation of an EAFA plan in 2013.

Southern Lake Malawi: Fisheries and Aquaculture

Description of the southern Lake Malawi fishery

The southern part of Lake Malawi (Figure 1) is composed of the southwest arm and southeast arm, both being the most productive fishing areas mainly for chambo and other cichlids. The area lies between longitude 34°5' and 35°5' and latitude 13°5' and 14o5'S and comprises more than 10% of the total surface area of the lake (28,800 km^2; Kanyerere et al. 2010).

Status of the fisheries

Both large-scale and small-scale fisheries operate in southern Lake Malawi. The large-scale fisheries are mechanized operating trawls, purse seines, or lift nets. The small-scale fisheries include all fishers that use engines of less than 20 hp or canoes without engines to catch fish. Gears used in the small-scale fisheries include beach seines, open-water seines, gill nets, fish traps, longlines, and hand lines (Banda et al. 2001).

The 2013 frame survey showed that there were 58,432 small-scale fishers recorded in Malawi out of which 26.5% were from southern Lake Malawi. There were 26 licensed large-scale fishers operating in southern Lake Malawi in 2012 (GoM 2014). While there has been a general increasing trend of fish harvests of most of the fish species mainly from 2007 to 2011, chambo harvests have remained low (Figure 2).

The fish harvest is largely composed of a pelagic cyprinid, usipa *Engraulicypris sardella*, which has masked the decline of commercially valuable chambo harvest (Hara 2006, 2008; Weyl et al. 2010, cited by Hara and Njaya 2016; Tweddle et al. 2015). Changes in the fish composition were also reported by fishers, beach village committees[1], beach village subcommittees, traditional leaders, fish processors, and fish traders during a field survey (Hara 1996; Njaya 2013). Other important harvested fish species that are both cichlids include kambuzi (*Lethrinops* spp.) and utaka (*Copadichromis* spp.)

The decline in chambo species in southern Lake Malawi has been reported since the late 1980s (FAO 1993). Excessive use of trawling operations, nkacha (open-water seining), beach

[1] A beach village committee is composed of people engaged in fishing-related activities (fishing, processing, and trading) at a particular beach while a beach village subcommittee is the elected body of 10–12 members representing interests of the beach village committee.

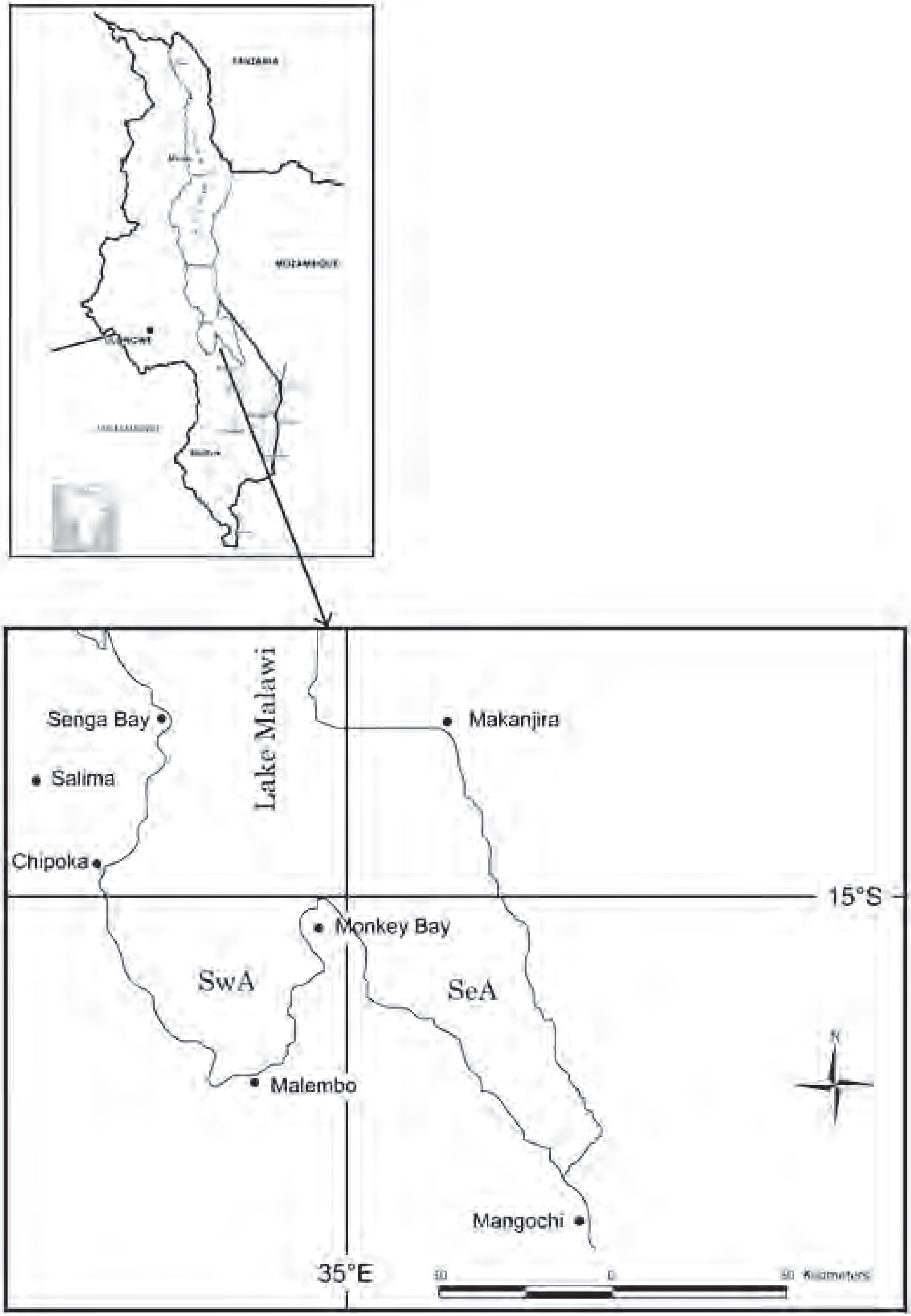

Figure 1.—Map of Malawi (top) and southern Lake Malawi (below) showing the southeast arm (SeA) and southwest arm (SwA). (Source: Hara and Njaya 2016).

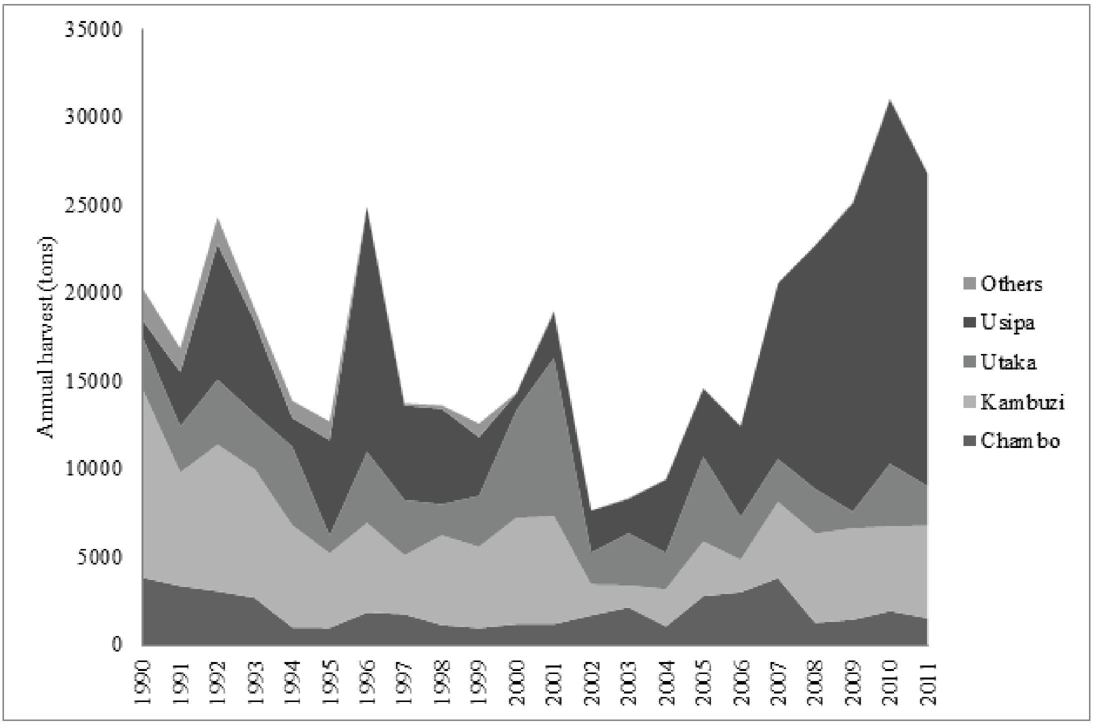

Figure 2.—Estimated annual fish harvests from southern Lake Malawi from 1990 to 2011. (Sources: GoM 2012, 2014; Hara and Njaya 2016).

seines, and undersized mesh gill nets were the reasons the Food and Agriculture Organization of the United Nations cited, which were supported by respondents in a subsequent field study (Njaya 2013). Other reasons include habitat degradation, population growth, and climate change and variability (Banda et al. 2005).

Status of aquaculture

The aquaculture subsector plays a significant role in Malawi's population as a source of food, income and employment, with fish yields estimated at 4,000 metric tons annually (GoM 2014). Within Mangochi, there are 392 small-scale fish farmers owning 603 ponds and one commercial aquaculture investor engaged in both pond and cage farming. The small-scale fish farmers collectively produce only 25 metric tons per year. While the commercial fish farm that was established in 2004 recorded weekly harvests of about 10 metric tons in 2007 from about 50 cages (Harley 2009).

Why Use the Ecosystem Approach to Fisheries and Aquaculture in Southern Lake Malawi?

In southern Lake Malawi, the commercially valuable chambo is overexploited and no further increase in yield is expected (Banda et al. 2005; Hara and Njaya 2016). Annual chambo harvests have been less than 2,500 metric tons per year since the late 1990s (Njaya 2013; GoM 2014).

The fisheries sector contributes approximately 2% to Malawi's gross domestic product (de Graaf and Garibaldi 2014) and is a significant source of employment by directly employing about 60,000 fishermen, and indirectly more than 500,000 people being engaged in fish processing, marketing, net making, boat building, and engine repair (GoM 2012). Malawi's population was estimated to be 13.1 million in 2008, which resulted in decreased per capita fish consumption from more than 12 kg in the 1970s to less than 7 kg in the 2000s (NSO 2008;

GoM 2012). Additionally, Lake Malawi is considered a global biodiversity hot spot for wild fish. Therefore, overuse of the resources and loss of diversity pose serious socioeconomic and ecological threats to the livelihoods of the fishing communities and the fishery resources.

Environmental and social impacts are vital in aquaculture development. Considerations should be made on some specific issues about ecological services such as waste disposal and sedimentation, and ecosystem services such as water for fish and fisheries and domestic use (GoM/FAO 2014). Pollution is also a threat from cage culture in the southern Lake Malawi if commercial aquaculture continues to expand (Gondwe 2009). An ecosystem approach is essential to incorporate the views and priorities of the stakeholders in the formulation of management plans.

Challenges and Lessons Gained from the EAFA Planning Process

Several lessons were gained during the EAFA planning process. Key ones included setting objectives, defining boundaries, ensuring extensive consultations, getting commitment and participation of stakeholders, reducing overdependence on fishing, addressing the open access nature of the fishery, reducing conflicts, and improving the limited availability of data.

Setting policy objectives

The process of EAFA planning is challenging when it comes to setting policy objectives, indicators, and targets to balance both human and biological considerations, as EAFA requires (Hara 2013). While an attempt was made in the previous Chambo Restoration Strategic Plan to set targets to achieve an annual harvest of 10,000 metric tons after a 10-year implementation period, in the EAFA plan, targets were not set for rebuilding the chambo populations. Appropriate data for modeling were limited, implying that monitoring and evaluation of the EAFA would be difficult.

The Government of Malawi and the Food and Agriculture Organization of the United Nations (GoM/FAO 2014) reported that during the community consultative meetings, stakeholders agreed on the following as policy recommendations:

- Adopt a multidisciplinary approach in aquaculture to avoid a narrow fishery-sector perspective;
- Poverty and food and nutrition security goals and strategies should be explicit in fisheries and aquaculture sector policy;
- Ensure coherence between major cross-sectoral development policies, programs, and sectoral policy;
- Develop a policy that seeks to maximize resource rents and export revenues;
- There should be a policy that supports local and regional market development and local multiplier effects;
- Small-scale integrated agriculture aquaculture (IAA) systems should be promoted as a vehicle to enhance diversity, resilience, and output of the total farm system;
- Small and medium aquaculture produc tion systems (SMEs) can enhance local economic development if well planned and implemented;
- Given the uncertainty of climate change impacts, policies that promote a diversity of production systems and products should lead to greater economic and social resilience than specialization on a small range of products and systems; and
- Training in various aquaculture systems could provide new opportunities for unemployed people including the youth and women for their improved livelihoods.

Setting objectives based on the above recommendations was difficult mainly due to inadequate and unreliable data for analysis and subsequent policy guidance. Additionally, without adequate capacity in terms of human resources and funding, implementation of the plan could be difficult. This situation could be similar to the previous one whereby the Chambo Restoration Strategic Plan was formulated but could not be fully implemented. Staples and Funge-Smith (2009) also recommend the need to consider long-term political will with sufficient resources and short-term economic and social support for implementation of EAFA. They also noted that EAFA requires commitment by stakeholders to address the challenge of making choices that require trade-offs and compromises among different sectors of society.

Defining boundaries

During formulation of the EAFA plan, it was difficult to agree on the project boundary, which could negatively affect resource allocation and implementation. Eventually, it was generally agreed that at least all villages along the lakeshore should be targeted (Njaya 2013). However, a broader boundary that included the entire watershed would have been more appropriate. Although some of the watershed areas are far away from the lake, they are important as sources of water and conservation of vegetation to minimize soil runoff and subsequent siltation of the influent rivers, which provide spawning grounds for chambo and other fish species.

Extensive consultations

Community consultations are always recommended for any project formulation for buy-in to facilitate its implementation (Staples and Funge-Smith 2009). However, it might also be costly if the process is not well planned. During the EAFA plan development, some issues could be tabled several times despite agreements reached in the previous meetings. This arose due to either having some participants who were attending the meetings for the first time or who did not remember previously agreed-upon decisions.

Commitment and participation of stakeholders

It is not easy to measure the commitment of stakeholders, especially where community meetings are financially supported by external agencies. Lessons could be drawn from the past comanagement initiatives, which could enable stakeholders to attend Lake Malombe beach village community meetings largely due to financial inducements provided by projects (Hara 1996). The stakeholders must be made aware that participation in the EAFA process is in their best interest.

As much as EAFA was meant to accommodate various sectors at district level, participation during consultative meetings lacked representatives from key sectors such as water resources, marine, and agriculture. A problem with this limited participation will be weak support from the respective key sectors, which may affect project performance and outcomes. It was also noted that there was limited participation from the private sector, local government, and women, yet these groups are crucial in terms of their dependence on the fishery resources. Lack of commitment and insufficient participation will result in an EAFA plan that lacks ownership and will not be sustainable.

Reducing overdependence on fishing for livelihood

Limited alternative livelihood strategies for the fishing-dependent communities may undermine success of the EAFA. Hara (2008) also asserts that fishing in Malawi is considered a business venture and livelihood activity for many people in their respective communities. Therefore, fisheries management measures such as closed seasons, which limit the economic returns of fishers, are usually resisted, resulting in noncompliance to fishing regulations.

Limited access to the fishery

The question about limited access was debated by stakeholders without conclusion during several community consultative meetings. The main issue concerned identification of other income generating activities for the fishers that would be taken out of fishing. A similar observation was made during the initial stages of the Lake Malombe participatory fisheries management program in the early 1990s. An arrangement was made to compensate all open-water seine (nkacha) fishers that were willing to stop fishing. However, after a second thought, the plan was cancelled because it was considered unsustainable (Njaya 2002). It is yet to be seen if during the EAFA implementation process a similar scheme would be considered to reduce the number of fishers.

Reducing conflicts

Formulation of strategies to resolve various conflicts in the project site might be difficult. There are conflicts between investors (cage owners) and small-scale fishers that operate their gears close to where cages are installed. There are also conflicts between small-scale and large-scale fishers in terms of fishing zones as illegal trawlers are seen fishing in shallow waters where gill-net and seine fishers operate. Cases of gill nets getting damaged are common, which affects the livelihood of the small-scale fishers.

There is also promotion of irrigation along influent rivers, which results in soil erosion and siltation of rivers thereby reducing reproductive capacity of cyprinids. And there are conflicts between small- and large-scale fishers on fishing times and fishing areas. Trawling with large-scale fishing boats with engines above 44 hp is allowed from 0600 to 1800 hours while gill-net fishers are allowed to set their nets from 1800 to 0600 hours. However, at times, the large-scale fishers break the law by trawling at night, during which they cause damage to the set gill nets. The small-scale fishers also complain about continued illegal trawling operations within the shallow areas (less than 18 m deep) of Lake Malawi, which are not designated for large-scale fishing (GoM/FAO 2014).

Improving limited baseline data

There were limited baseline data available to enable a meaningful planning process, including development of indicators. Of particular importance were data to verify the level of pollution, climate change impact on the fishery resources and livelihoods of the dependent communities, and biological and stock level data on some offshore deepwater fisheries species like catfish (*Clarias* spp. or *Bathyclarias* spp.) that would provide a basis for fishing investment and interactions among sectors and actors. Limited availability of such data would lead to a poor EAFA plan and consequently fail to address the declining chambo harvests.

Conclusion

This paper has shown that the EAFA process is difficult; hence, certain issues should be considered during its planning and implementation stages. Of critical importance is the need to properly set policies, define the project site, identify relevant stakeholders, and consider property rights issues. There are emerging conflicts among fishers and between the fishers/fish farmers and fishery managers that mainly arise to due weak governance and enforcement and conflicting policies.

Therefore, there is a need for governance and policy reforms that would consider balancing human and ecological issues based on the EAFA framework. The development of the EAFA needs to consider rights-based management, which is difficult to tackle within the small-scale fisheries for sustainable use of fisheries resources (Hara and Njaya 2016). With political will and adequate capacity in terms of skilled manpower and financial resources, and active and effective participation of the stakeholders, EAFA seems a viable strategy for the recovery of the declined chambo stocks that would contribute to the increased resilience of fisheries, environment, and sustainable livelihoods of the resources users.

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The Prospect for Regional Governance of Inland Fisheries in Central Eurasia

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Abstract.—The successor states to the former Soviet Union located in Central Asia and the Caucasus have substantial challenges in promoting sustainable inland and small-scale fisheries. This is particularly true due to the impact of the energy–water nexus that characterizes the domestic development challenges of the eight countries. Soviet policies on water usage for misguided agricultural development, including the cotton monoculture effort in Central Asia, depleted important water flows to traditional fisheries while more recent pressure for increased hydroelectric generation capacity within new national borders threatens to disrupt traditional fisheries and wildlife habitat. International tensions deriving from competing claims to river flows constrain regional cooperation and portend political and perhaps military conflict. There has been progress in regional economic integration among the Caspian basin littoral states, and in the context of the Economic Cooperation Organization, the Shanghai Cooperation Organization, and the emerging Eurasian Economic Union, but suspicions as to motives held by key sponsoring states remain, as do perceived national interest conflicts. This paper explores the constraints and prospects for regional cooperation and governance, taking into account regional and bilateral tensions and drivers. Recommendations for future progress are proposed.

Introduction

Achieving comprehensive global governance of fisheries remains a challenging task. However, regional and national governance structures may provide insights for global fisheries governance. There are some important successes in North America, particularly in the East (e.g., Atlantic Cod *Gadus morhua*, Atlantic lobster *Homarus americanus*) and the West (Pacific Salmon *Oncorhynchus* spp.). In addition, the framers of the European Union (EU) Common Fisheries Policy (CFP) can point to some success in remediating the collapse of fisheries in northern European waters by reducing the size of fleets in key countries and by enforcing limitations on equipment, fishing seasons, and catch size. This approach applies to coastal and marine fishing more than inland fisheries, but national regulation of the latter seems rather effective in many EU countries, particularly in the North. That being said, there are many criticisms on the implementation of the EU CFP by national authorities, and the call for much more serious regional and global action has been made with clarity and urgency (Lequesne 2004; Schechter and Blue 2011). The EU has been relatively aggressive in addressing overfishing, and rightly so, given that the traditional fisheries of its members have been some of the most overfished in the world. The health of fisheries in the Mediterranean basin is also affected significantly by pollution that has a wide

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range of residential, agricultural, and especially industrial sources, some of which are under scrutiny and have been targeted for cleanup (see European Parliament 2013 and European Commission 2015).

This paper addresses several interrelated questions about global fisheries governance. What is the prospect for governance of regional inland fisheries in the post-Soviet successor republics of central Eurasia? What, if anything, can be learned from the (partial) success stories of fishery governance in North America and Europe? Are the challenges similar? Are there best practices and knowledge that can be transferred? In short, I argue that the EU CFP does provide some important lessons for central Eurasia, but the regional tensions over water and energy usage remain serious impediments. Moreover, there are related domestic economic and political constraints, evident since independence, which both have helped to worsen the collapse of inland fisheries in the region and now stand in the way of short-term remediation. The promoters of the Eurasian Economic Union have the ambition to mimic the sectoral policies of the European Union, including water, energy, and fisheries policies, but the commitment of resources and policy convergence is minimal, to date. Indeed, the Central Asian and Caucasus Regional Fisheries and Aquaculture Commission (CACFish) within the Food and Agricultural Organization of the United Nations (FAO) represents the most promising institutional forum at present in the region, despite its recent inception.

Origins and Dimensions of the Inland Fisheries Crisis in Central Eurasia

The collapse of inland fisheries in Central Asia and the Caucasus derives in large part from the energy–water nexus in the region (see International Crisis Group 2002; World Bank 2004; FAO 2009; Thorpe et al. 2009; Breckle et al. 2012). Countries with abundant water resources are deficient in fossil fuel resources and vice versa, so there is pressure on water-rich countries to increase hydroelectric generation capacity, which is opposed by downstream oil-rich and gas-rich countries that require substantial water flows for elaborate irrigation efforts of cotton crops (see International Crisis Group 2005). Added to this imbalance is the legacy of misguided, noxious Soviet agricultural and environmental policies that diverted water resources for unsustainable agricultural production goals yet permitted unfettered industrial pollution of rivers, lakes, and seas. The Soviet water and energy transmission network may have made some sense in Moscow for autarkic economic and heavy industrialization goals under Stalin and his immediate successors, but the damage done to the natural environment and the prospect for sustainable habitation and prosperity in the Soviet successor republics was and is appalling. The network of water and energy transmission managed centrally from Moscow in Soviet times has disintegrated into decaying infrastructures managed by national authorities beset with conflicting domestic imperatives and seemingly myopic policy priorities and been complicated by limited economic resources.

The dimensions of the inland fisheries crisis in Central Asia and the Caucasus are startling, as Tables 1 and 2 clearly show. There was a dramatic drop in the fish harvest in all countries in the region from 1989 to 2008. Armenia seems to be the least affected of the eight countries, but even in this country the 2008 harvest was less than 78% of the 1989 harvest. In Azerbaijan, Kyrgyzstan, and Tajikistan, harvest dropped to below 10% of the 1989 levels, 2.9%, 6.9% and 4.9%, respectively. By 2012, several countries had made significant progress in achieving harvest levels similar to the 1989 levels (Table 2). Some of this progress, especially in Armenia and Uzbekistan, is attributable to aquaculture development, rather than by restoring inland fisheries (Table 2).

The reasons for the reduction in harvest are complex and include a number of distinctive, country-specific factors. Thus, there is no space for a full country-by-country analysis in this modest paper. The four key reasons that apply to several of these countries are delineated to explain the continuing roadblocks to remediation through improved regional cooperation.

Table 1.—The collapse of fish harvest (metric tons) in Central Asia and the Caucasus. (Sources: FAO 2010–2014, 2011a, 2011b).

	1989	2008	2008 production as % of 1989 output	2012
Armenia	7,371	5,701	77.3	9,711
Azerbaijan[a]	55,000	1,606	2.9	1,272
Georgia[a]	152,042	26,692	17.6	12,720
Kazakhstan[a]	89,508	55,902	62.5	43,250
Kyrgyzstan	1,447	100	6.9	324
Tajikistan	3,547	172	4.9	1,404
Turkmenistan[a]	52,974	15,016	28.3	15,017
Uzbekistan	25,526	6,218	24.3	10,700
Total	387,415	111,407	28.8	94,403

[a] Includes marine capture—Black and Caspian seas.

First, the collapse of the Soviet economy was dramatic and far-reaching. With the downfall of the Soviet Union as a political entity, the tasks for each successor state to address the dual challenges of building a new political and economic system were immense. The common western model of democratization and economic liberalization was largely bypassed in this region, except perhaps for Georgia, beginning with its 2003 Rose Revolution. This resulted in President Eduard Shevardnadze, a holdover from the Soviet era, being forced to resign, leading to presidential and parliamentary elections in which Mikeil Saakashvili's United National Movement party won. When some elements of the suggested reforms were adopted in most other post-Soviet countries, these were only modestly effective. The literature explaining this story is detailed but too large to address here systematically (see Lavigne 1999; Aslund 2002, 2007; Peimani 2002; Olcott 2005, 2010, 2012; Overland et al. 2010). The predominant system now in place is aptly depicted as "patronal politics" by Henry E. Hale (2015).

Second, the long-term negative environmental impacts of policies that began under the Soviet regime affected all eight successor countries to some extent, destroying habitat and reducing, and sometimes eliminating, formerly productive fisheries. These actions were long in the making and not easily remediated. However, the most striking fact is that until recently, and then only partially, none of the successor countries' regimes sought to address the

Table 2.—The collapse of fish harvest (metric tons) in Central Asia and the Caucasus. (Sources: FAO 2010–2014, 2011a, 2011b). f = failed to report on time; Food and Agriculture Organization of the United Nations estimate.

	1989 total	2008 total	2012 capture	2012 aquaculture	2012 total
Armenia	7,371	5,701	861	8,850	9,711
Azerbaijan[a]	55,000	1,606	911	366	1,272
Georgia[a]	152,042	26,692	12,070	650f	12,720f
Kazakhstan[a]	89,508	55,902	43,000f	250f	43,250f
Kyrgyzstan	1,447	100	27	297	324
Tajikistan	3,547	172	923	481	1,404
Turkmenistan[a]	52,974	15,016	15,000f	17f	15,017f
Uzbekistan	25,526	6,218	4,000f	6,700f	10,700f
Total	387,415	111,407	76,792	17,611	94,403

[a] Includes marine capture—Black and Caspian seas.

harmful effects of wasteful irrigation used to grow inappropriate crops, like cotton and rice in excessively arid regions, polluting practices that had disrupted fish habitat, or sought to pursue less expansive hydroelectric generation strategies. The desertification of the Aral Sea in Kazakhstan and Uzbekistan is a well-publicized case study and the most striking example of this tragic set of policies. The elimination of this formerly productive fishery had obvious direct impacts on the livelihoods of the fishers, but the nearly complete destruction of the subregion and its broader population through the secondary impact of soil encrusted with salt and poisoned by pesticide runoff, which then spread through the air in the common regional dust storms, was nothing short of devastating. Breckle et al. (2012) and Micklin et al. (2014) provide a detailed analysis and assessment of this fishery, but it still remains clear that newly independent governments generally chose not to repeal many Soviet policies and the system that had wreaked havoc on fish habitat and the broader environment (FAO 2003, 2009). The Soviet imperial policies of autarky and self-sufficiency (especially the policies behind the cotton monoculture focus in Central Asia) were no longer in play as a political justification for bad economics and agriculture, especially in the increasingly globalized economy of the post-Cold War world (Figure 1).

Third, one can argue that the political leadership in each country was distracted by more pressing governance and economic development challenges in the early years of independence. For Georgia and Tajikistan, civil war raged on during the early years. For Armenia and Azerbaijan, the devastating conflict over Nagorno-Karabakh was a serious distraction and obvious impediment to regional cooperation on remediating the pollution of key transborder river systems. More subtle, but nonetheless extant, was the fact that most of the regimes were highly focused on other elements of economic

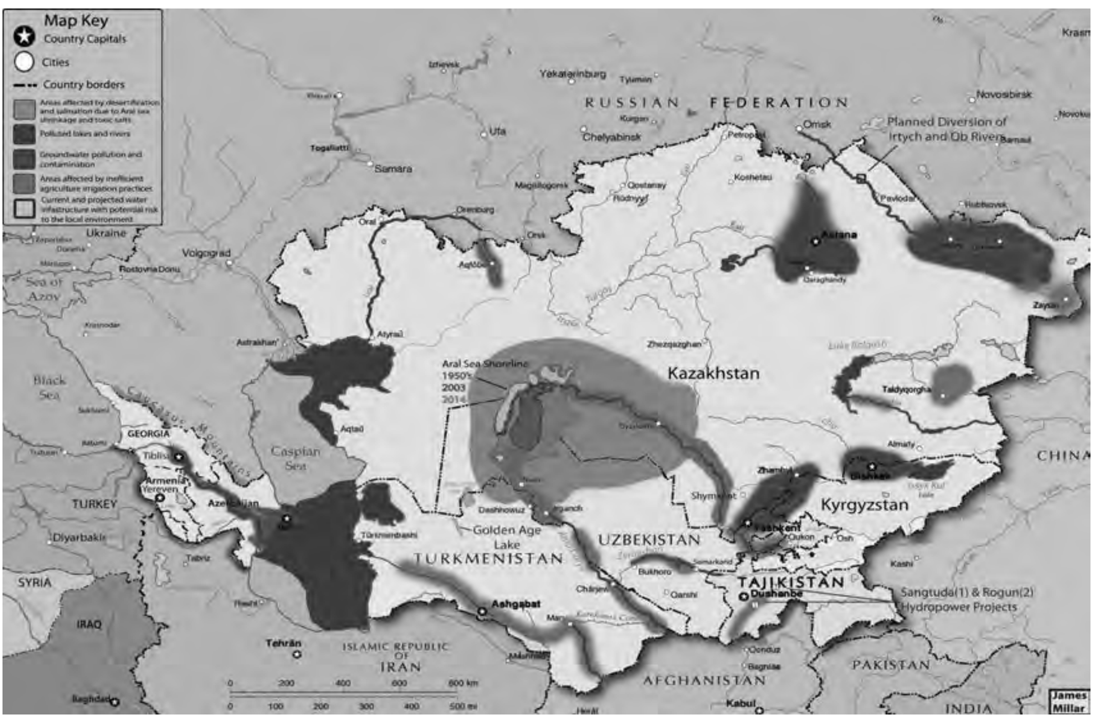

Figure 1.—Areas affected by desertification, polluted water bodies, polluted groundwater, inefficient agricultural irrigation practices, and current and projected water infrastructure with potential risk to the local environment. (Produced by James Millar, James Madison College, Michigan State University).

and development policies. Fishery policy was not a high priority, nor was general agricultural reform and rural development. One notorious example of this posture in Sakashvili's Georgia was the widely quoted, bold claim made by a central bank official that rural farmers should "move to the cities," a statement offered in response to complaints about the growth in rural poverty from the evident neglect of agricultural development in a republic formerly known for its agricultural productivity during the Soviet era (Echanove 2013; Archilochus Melikadze, Agricultural Projects Management Agency and Eric Livny, International School of Economics at Tbilisi State University, personal communications). The new economy of Georgia was focused on the global information and communications revolution, not resuscitating something mundane such as food production.

The fourth set of factors that explain the collapse of inland fisheries has to do with the crucial energy–water nexus operative in much of the Central Eurasian region. Countries with abundant water resources (e.g., Georgia, Kyrgyzstan, and Tajikistan) are deficient in fossil fuel resources, while oil- and gas-rich countries (e.g., Azerbaijan, Kazakhstan, Turkmenistan, and Uzbekistan) are downstream from and dependent on the water-rich countries for agricultural irrigation and fisheries. The pressure on water-rich countries to increase hydroelectric generation capacity is clear. But such action is often opposed by downstream oil- and gas-rich countries, especially in Central Asia, which claim a right to substantial water flows for elaborate irrigation efforts in support of the cotton monoculture, and secondarily for fishery rehabilitation (ICG 2005). Armenia has modest water resources, mostly from the mountains of Turkey, but has no significant oil or gas reserves. In some ways, it is the least independent of the Central Eurasian countries, but Armenia enjoys substantial political and military support from the Russian Federation and equally substantial economic support from the Armenian diaspora.

Countries with abundant water resources have generally not been able to monetize their water resources, at least not in comparison with what the oil- and gas-rich countries have been able to do. Indeed, schemes to compensate water drawdown with energy resource transfers, the subject of serious negotiation and some agreements, most notably between Uzbekistan and Tajikistan, have not worked well (World Bank 2004). The Uzbeks have threatened recourse to military action in response to potential cuts in water flows (ICG 2002). The energy–water nexus is clearly a challenge, as Tajikistan and Kyrgyzstan, on the one hand, and Uzbekistan and Kazakhstan, on the other, seem to court serious conflict over the hydroelectric generation plans of the former in competition with the downstream irrigation needs of the latter. Irrigation needs are problematic due to aging and poorly maintained structures, harsh climate, and soil quality deficiencies, but they are also driven by the surprising longevity of Soviet cotton monoculture in the region. A Russian or Chinese role in helping to reduce tension and remediate the conflicts of interest, which the Soviets helped to create, would be a valuable contribution to the region, whether it comes bilaterally or as part of a larger multilateral effort.

Georgia and Tajikistan offer the best examples of a predominant focus on hydroelectric generation capacity development, sometimes without due consideration of fish habitat impacts. Georgia has been engaged in a sustained effort to expand its hydroelectric power generation capacity for many years. A large number of construction and rehabilitation projects have been initiated. Various government assessments suggest that at least 15 new hydropower plants should be constructed because at present, Georgia is using less than a fifth of its hydroelectric power potential (Figure 2). The plan is to provide sustainable (i.e., year-long) power to meet Georgia's growing demand, as well as to increase substantially its electricity exports. Georgia is fortunate to have 26,000 rivers, constituting 60,000 km in total length, many of which originate in mountainous terrain. Estimates suggest that at least 300 rivers are suitable for hydroelectric development. Georgia's 2008 Renewable Energy Plan was quite ambitious in this respect. Financing the plan remains a serious challenge, making Georgia dependent on external funding sources like the World Bank and the Asian Devel-

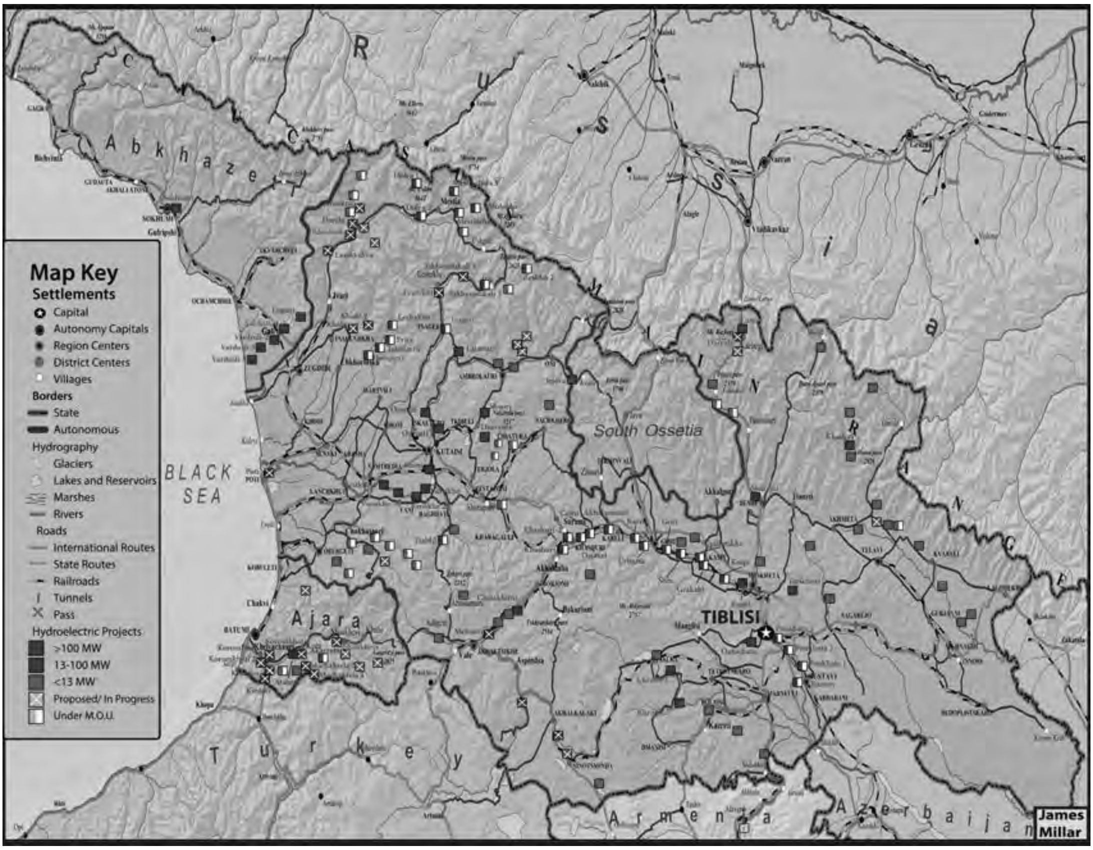

Figure 2.—Hydroelectric power plants and networks in Georgia. (Produced by James Millar, James Madison College, Michigan State University).

opment Bank, which require environmental and social impact assessments, to the frustration of the aggressive energy project planners. There is, however, little or no attention to impact on fish habitat in the hydroelectric expansion plans.

For Tajikistan, the key dam constructions are the Rogun and Sangtuda hydropower projects (Figure 1). Rogun is set to solve Tajikistan's annual winter energy crisis with an expected installed capacity of 3,600 MW. Unfortunately, it may also displace 42,000 people from surrounding mountain villages. The World Bank has not yet committed financing to the project, but the Tajik government appears ready to complete it eventually in any case, perhaps with Russian or Chinese support.

Finally, it is often argued that the key obstacle poorer Central Eurasian states face is the lack of investment funds to modernize and rehabilitate neglected aquaculture and inland fishery equipment. Indeed, there is a tendency to focus the limited financial and manpower resources on crops, like rice, tobacco, and wheat in Kyrgyzstan (FAO 2007) and urban development and hydroelectric generation projects in Georgia (FAO 2005, 2010). Inadequate funding is likely a long-term constraint, but regional cooperation to share and regulate water resources more equitably and sustainably is not impossible (see World Bank 2004). Aquaculture is under modest development in several Central Eurasian countries, most notably Azerbaijan, Georgia, and Kazakhstan, with the aim of restoring more self-sufficiency and diversity in food production. But the prospect for a substantial increase in public funding for expanded production in the current climate of low oil and gas prices is dim.

Conclusion

Are there regional institutional options that might help facilitate international cooperation on inland fisheries in Central Eurasia? The Commonwealth of Independent States, the Shanghai Cooperation Organization, the Economic Cooperation Organization, the Eurasian Economic Union, and CACFish are the principal institutional candidates, but frankly there is little reason for confident optimism in each institution for a variety of reasons. This results from the weakness of the institutions now available in the Central Eurasian region, and the lack of perceived common interest and trust among the successor states that constitute the membership(s). Certainly, there is no common willingness to accept supranational authority and effective regulation to the extent that has emerged with the EU CFP, and while some individual states in Central Eurasia enjoy substantial income from oil and gas exports at times, the prospect for a substantial regional pool of financial resources for investment in fisheries remediation and sustainability projects seems unlikely in the short term. Scientific expertise and technical assistance possibilities are available, but financial resources and political will are in short supply.

The Central Asian and Caucasus Regional Fisheries and Aquaculture Commission is in some ways the most promising institutional development in the region for tackling the fisheries crisis. It is not burdened with the political agendas of key regional powers like China, Russia, Iran, and Turkey, and it is backstopped with the technical expertise and experience of FAO. The Central Asian and Caucasus Regional Fisheries and Aquaculture Commission began its work in 2010 after Armenia, Kyrgyzstan, and Tajikistan ratified the CACFish founding agreement. There now have been several meetings of the CACFish Technical Advisory Committee, which have reviewed various aspects of the status of fisheries and aquatic resources in the region. The Central Asian and Caucasus Regional Fisheries and Aquaculture Commission has the power to impose binding management and conservation recommendations, but it has mainly focused on data collection and review, such as its inland fisheries stock assessment discussed in Bishkek in April 2014. The membership now includes Azerbaijan and Turkey. Georgia, Kazakhstan, Mongolia, Ukraine, and Uzbekistan also attended the third session of the commission held in Baku, June 2–4, 2014 (FAO 2012, 2014a, 2014b).

The way forward for Central Eurasia's inland fisheries is relatively straightforward, albeit politically challenging: (1) adopt and enforce regional and complementary national rules on fishing equipment and catch limits to curtail overfishing; (2) address transborder water sharing, conservation, and management aggressively on a regional basis before the resources are degraded beyond recovery; (3) continue to expand aquaculture research, development, and commercialization to replace collapsed fisheries that cannot be revived; and (4) expand essential hydroelectric generation capacity in Kyrgyzstan and Tajikistan but do so within a framework of environmental impact assessment that includes consideration of alternative strategies to reduce potential fish habitat loss, as well as efforts to limit human dislocation and transborder tensions. The way is straightforward, but the required level of political commitment and compromise will not come easy given the nature of the present Central Eurasian regimes (Hale 2015).

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From Ideas to Action: Ten Steps to Responsible Inland Fisheries that Support Livelihoods, Food Security, and Healthy Aquatic Ecosystems

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Abstract.—For decades, inland fisheries and their value have been overshadowed by marine fisheries dominated by the commercial sector. However, there is growing recognition that inland capture fisheries harvest is substantial. Indeed, inland fisheries generate many ecosystem services, most notably their contributions to food security and livelihoods. Here, we present the outcomes of a conference where scientists, resource managers, policymakers, and community representatives from across the globe gathered to discuss inland fisheries. What emerged from discussions at the conference is affectionately termed "The Rome Declaration," which provides a forward-looking call to action characterized by 10 recommendations: (1) improve the assessment of biological production to enable science-based management, (2) correctly value inland aquatic ecosystems, (3) promote the nutritional value of inland fisheries, (4) develop and improve science-based approaches to fishery management, (5) improve communication among freshwater users, (6) improve governance, especially for shared water bodies, (7) develop collaborative approaches to cross-sectoral integration in development agendas, (8) respect equity and rights of stakeholders, (9) make aquaculture an important ally, and (10) develop an action plan for global inland fisheries. We trust that the outcomes from this conference (including "The Rome Declaration") will serve as a catalyst for sustained action by the global inland fisheries community to ensure that fish and fisheries are accounted for and incorporated into broader water-resource management discussions and frameworks.

Context

Inland fisheries took center stage in January 2015 in Rome at the Food and Agriculture Organization of the United Nations (FAO) headquarters when scientists, resource managers, policymakers, and community representatives from across the globe gathered. Participants discussed the current state of inland fish and fisheries, explored the interactions among the sectors that impact freshwaters, and developed recommendations for the governance and management of sustainable aquatic ecosystems to ensure that inland fish and fisheries prosper to continue to support livelihoods and food security (FAO and MSU 2016). As discussed by Beard et al. (2016, this volume), this requisite global conference was long overdue, despite inland fish and fisheries generating crucial ecosystem services (Cowx and Portocarrero Aya 2011; Lynch et al. 2016, this volume).

For many decades, inland fisheries and their value have been overshadowed by marine fisheries dominated by the commercial sector (Cooke et al. 2014; Youn et al. 2016, this volume). However, there is growing recognition that inland capture fisheries harvest is substantial (Welcomme et al. 2010; Welcomme 2016, this volume). Nevertheless, estimates of global inland fisheries harvest have been plagued with problems and may underestimate actual harvest by several-fold (Bartley et al. 2015). De Graaf et al. (2015) suggested that a major constraint on data collection in inland fisheries results from their dispersed nature, which cannot be fully assessed using traditional approaches. As such, Lymer et al. (2016a, this volume) used a novel approach to estimate net primary production by continent and aquatic habitat type and thereby generated estimates of potential global inland fisheries annual production. The authors estimated that the global theoretical potential annual inland fisheries production is, on average, 6.5 times higher than the official catch data submitted annually to FAO and emphasized that the potential economic and social value of inland capture fisheries and their contribution to food security and livelihoods is much higher than estimated by the harvests currently reported.

The reason that so much effort has gone into better estimating global, regional, and local inland capture fishery harvest is that without a concept of harvest, it is difficult to make direct comparisons to the marine realm or accurately characterize and value the socioeconomic or nutritional benefits arising from these freshwater resources (Beard et al. 2011). As such, inland fisheries and inland aquatic ecosystems are often forgotten in high-level policy decisions, including international agreements and instruments related to water resource management. This has become exceedingly clear as major watercourses that transcend developing countries in South America (Amazon), Africa (Congo), and Asia (Mekong) face the prospect of intense hydropower development and where the sustainability of inland fish and fisheries (and the peoples they support) are considered unimportant relative to the potential for hydropower development (Winemiller et al. 2016). For example, the replacement costs for lost protein and nutrients from inland fisheries harvest in the Mekong River are significant (Lymer et al. 2016b, this volume) yet these human costs of hydropower development are rarely considered (Barlow 2016 this volume). Even the tiniest of fish in inland waters can provide essential protein, minerals, and vitamins to support children during critical life periods in developing countries (Roos 2016, this volume), yet the value of such fisheries are often dismissed when compared to the economics of hydropower or other water users (e.g., irrigation, industrial manufacturing). Opportunities certainly exist for better interfacing inland fish production with crop production (e.g., integrated fish–crop production systems; Phosa 2016, this volume) and supporting the development of inland aquaculture (Ibengwe 2016; Kahn 2016; both this volume).

Unlike marine fisheries that are traded globally and where exports can be easily tracked and quantified (Youn et al. 2016), most inland fisheries are small-scale fisheries where products are sold, bartered, or traded locally (Welcomme 2016). As such, those that attempt to estimate harvest and consumption in such regions are often forced to rely on household surveys implemented as part of agricultural monitoring programs (Funge-Smith 2016; Simmance 2016; both this volume). Such approaches hold much promise for biological monitoring (Cooke et al. 2016, this volume) and determination of values of inland fisheries (Funge-Smith 2016). If coupled with other more traditional fisheries monitoring approaches that involve fisheries dependent and independent data (see Koehn 2016, this volume), resource managers have the potential to be able to make meaningful advances in the determination of global inland fish production and fisheries harvest and their contribution to food security and nutrition while also providing local fisheries managers with the information requisite to effectively manage and restore inland fish and fisheries (Koehn et al. 2016). Beyond the biology, there is also a need to characterize and recognize values that are more difficult to quantify but exceptionally important, such as ecosystem monitoring, cultural values, traditional knowledge, and rights of indigenous peoples (Boisneau 2016; Lumley et al. 2016; both this volume).

Although the concept and practice of fishery management is common, in reality fish are simply a small part of aquatic ecosystems and are best managed in the context of integrated water resource management (Unver et al. 2016, this volume). Watersheds are coupled social-ecological systems and thereby require a logical, coordinated approach to assessment, planning, and management. Of particular note is the fact that watersheds connect the waters with the surrounding landscape (Hynes 1975) and thus demonstrate effectively the intimate connection between people, their activities on the landscape, and the aquatic ecosystem, including fish. Although in theory the concept of integrated water resources management (or watershed management or some form of ecosystem management) is appealing, in practice there are many challenges with its implementation, especially at the scale of extensive river basins that transcend political boundaries (e.g., Baigún et al. 2016, this volume). Some have attempted such efforts but done so on a smaller scale (e.g., at the level of the Pampangan Swamp in Sumatra [Muthmainnah and Prisantoso 2016, this volume] or Lake Milawi in east Africa [Njaya 2016, this volume]), which is useful for engaging the local community (e.g., in comanagement) but often fails to recognize external influences (e.g., whatever is happening upstream or on land; Lynch et al. 2016). What is clear is that effective governance structures at institutional and spatial scales need to incorporate all sectors involved in water resource use, not only to ensure that fisheries are managed effectively, but to ensure the sustainability of freshwater ecosystems (Bartley et al. 2016, this volume). Comanagement or local management is necessary but needs to occur at scales that enable holistic perspectives (Lumley et al. 2016).

As the global conference on inland fisheries drew to a close at the end of January 2015, those that participated considered this to be the start of a journey rather than the terminus. In an effort to maintain, and indeed accelerate, progress related to more effective consideration of inland fish and fisheries in freshwater resource allocation decisions, a group of thought leaders assembled at the conclusion of the conference to consider next steps. What emerged from those discussions is affectionately termed "The Rome Declaration," which provides a forward-looking call to action characterized by 10 steps and implementation recommendations (FAO and MSU 2016). These steps and recommendations are general and not targeted to specific groups; however, numerous entities at various levels of government and society will need to work together for effective implementation. The recommendations build on, *inter alia*, the principles contained in the Convention on Biological Diversity, the *Voluntary Guidelines for Securing Sustainable Small-Scale Fisheries in the Context of Food Security and Poverty Eradication* (FAO 2015b), and the *Voluntary Guidelines on the Responsible Governance of Tenure of Land, Fisheries and Forests in the Context of National Food Security* (CFS 2012). As detailed in those instruments, for effective management and sustainability of freshwater ecosystems and their fisheries, it is critical to recognize and incorporate the rights of fishers, women, traditional resource users, and indigenous people into all levels of decision making. Past development of inland water resources has often occurred in the absence of such recognition and deprived key groups of culturally and economically important connections and access to aquatic ecosystems and the services they deliver.

Ten Steps

The 10 steps are presented in an order that represents a logical progression. For example, it is first necessary to know what exists and how valuable it is before information can be communicated cogently to all sectors (in the absence of such information, a precautionary approach is required). Moreover, fisheries cannot be integrated into cross-sectoral governance if they cannot be effectively managed within the fishery sector. Taking these 10 steps will be part of a path towards a world where people can responsibly use and enjoy freshwater ecosystems and their fishery resources today and for years to come.

1. Improve the assessment of biological production to enable science-based management

Accurate and complete information about fishery production from inland waters is lacking at local, national, and global levels. Governments often lack the resources or capacity to collect such information due to the diverse and dispersed nature of many inland fisheries. There is much scope for developing and refining biological assessment tools to facilitate science-based management.

2. Correctly value inland aquatic ecosystems

The true economic and social values of healthy, productive inland aquatic ecosystems are often overlooked, underestimated, and not taken into account in decision making related to land and water use. Economic and social assessment is often difficult and valuation often limited. In most cases, especially in the developing world, inland fisheries are part of the informal or local economy, so their economic impact is not accurately measured in official government statistics.

3. Promote the nutritional value of inland fisheries

The contribution of inland fisheries to food security and nutrition is higher in poor, food-insecure regions of the world than in many developed countries that have alternate sources of food. Good nutrition is especially critical in early childhood development (i.e., the first 1,000 d). Loss of inland fishery production will undermine food security, especially in children, in these areas and put further pressure on other food-producing sectors.

4. Develop and improve science-based approaches to fishery management

Many inland water bodies do not have fishery or resource management arrangements that can adequately address sustainable use of resources. Where management arrangements exist, compliance and enforcement are often minimal or nonexistent. This may result in excessive fishing pressure, decreased catch per unit effort, and conflicts between fishers, as well as changes in the productivity of fishery resources. In some areas, reductions in fishing capacity will be required. To facilitate fishery management, it will be important to improve access to and promote better sharing of data and information about inland fisheries supporting the assessment–management cycle.

5. Improve communication among freshwater users

Information on the importance of the inland fishery and aquaculture sectors is often not shared with or accessed by policymakers, stakeholders, and the general public, thereby making it difficult to generate political will to protect inland fishery resources and the people that depend on them. Moreover, many misconceptions exist on the needs and desires of fishing communities. Building from the small-scale fisheries guidelines (FAO 2015a) and other relevant instruments, use appropriate and accessible communication channels to disseminate information about inland fish, fishers, and fisheries to raise awareness of inland fisheries' values and issues, to alter human behavior, and to influence relevant policy and management.

6. Improve governance, especially for shared water bodies

Many national, international, and transboundary inland water bodies do not have a governance structure that holistically addresses the use and development of the water and its fishery resources. This often results in decisions made in one area adversely affecting aquatic resources, food security, and livelihoods in another.

7. Develop collaborative approaches to cross-sectoral integration in development agendas

Water-resource development and management discussions very often marginalize or overlook inland fisheries. Therefore, tradeoffs between economically and socially important water-resource sectors and ecosystem services from inland water systems often ignore inland fisheries and fishers. Development goals based on common needs (e.g., clean water and flood control) can yield mutually beneficial outcomes across water-resource sectors.

8. Respect equity and rights of stakeholders

Lack of recognition of the cultural values, beliefs, knowledge, social organizations, and diverse livelihood practices of indigenous people, inland fishers, fish workers, and their communities has often resulted in policies that exclude these groups and increase their vulnerability to changes affecting their fisheries. This exclusion deprives these groups of important sources of food, as well as cultural and economic connections to inland aquatic ecosystems.

9. Make aquaculture an important ally

Aquaculture is the fastest-growing food production sector and an important component in many poverty alleviation and food security programs. It can complement capture fisheries (e.g., through stocking programs) by providing alternative livelihoods for fishers leaving the capture fisheries sector and by providing alternative food resources. It can also negatively affect capture fisheries (e.g., introduction of invasive species and diseases) through competition for water resources, pollution, and access restrictions to traditional fishing grounds.

10. Develop an action plan for global inland fisheries

Without immediate action, the food security, livelihoods, and societal well-being currently provided by healthy inland aquatic ecosystems will be jeopardized, risking social, economic, and political conflict and injustice. Therefore, it is necessary to develop an action plan based on the above recommendations to ensure the sustainability and responsible use of inland fisheries and aquatic resources for future generations. The action plan should involve the international community, governments, civil society organizations, indigenous peoples groups, and private industry and include all sectors using freshwater aquatic resources.

Conclusion

From the outset, the intent (see Beard et al. 2016) was clearly to have a global cross-sectoral conference, involving and integrating the other freshwater resource sectors (e.g., agriculture, energy, and drinking water). Despite the best efforts of all involved, there were inherent difficulties in doing so. Of particular note was the difficulty in establishing integrated cross-sectoral management of freshwater resources. Although a laudable goal, this was not achieved, and thus, more work is needed. In the interim, fisheries professionals need to take a leadership role in this initiative on local scales (e.g., water body, subwatershed) in an effort to sustain global freshwater fish and fisheries. Hopefully, lessons learned at the local scale on how to implement integrated cross-sectoral management of freshwater resources (including fish) will provide insight on how to scale up such efforts to larger geopolitical contexts. It is also worth noting that this conference was the first step in a long process that will take time to fully realize. There were certainly meaningful outcomes and collective interest in real action (see "The Rome Declaration" above) and we trust that this will serve as a catalyst for sustained action by the global inland fisheries community to ensure that fish and fisheries are accounted for and incorporated into broader water resources management discussions and frameworks.

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This publication is a compilation of presentations and recommendations resulting from the Global Conference on Inland Fisheries: Freshwater, Fish and the Future, convened at the headquarters of the Food and Agriculture Organization of the United Nations in Rome, Italy in January 2015. This conference on the function and importance of inland fisheries brought together experts from various sectors and more than 40 nations, including a large number of early career scientists and women. This diverse group was essential because the challenges facing inland fisheries require new cross-sectoral approaches and the involvement of all stakeholders in freshwater resources.

All too often, the critical role of inland fisheries in food security and livelihoods is inappropriately valued, over even overlooked, when policymakers decide on the use, allocation, and alteration of freshwater resources in their communities and nations. The information in this book highlights this importance of freshwater fish, their habitats, and their fisheries to society. It aims to describe the current state of the knowledge and future information needs that will allow for fisheries sustainability, which in turn directly or indirectly provides for the health, well-being, and prosperity of human communities throughout the world.

The purpose of this book, and the global conference is to elevate the significance of freshwater fisheries throughout the world so that fishery managers and the people that depend on freshwater fisheries will have a voice when policymakers make decisions that impact their viability and productivity. It represents a unique output on inland fisheries from a global perspective that addresses biological and sociocultural assessments, drivers, and governance issues. Based upon the presentations and discussions of the conference, a set of recommendations were developed, "The Rome Declaration: Ten Steps to Responsible Inland Fisheries," which will provide a foundation for a new international approach to ensure that the true value of inland fisheries is recognized in resource allocation decisions.

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